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16. Abstract

This report summarizes an evaluation by the users of the National Airspace System (NAS) of those policy and technological issues critical to FAA Engineering and Development (E&D) initiatives.

Five topic groups were organized to evaluate the critical issues that must eventually structure a program of E&D initiatives, as follows:

(1) Productivity and Automation,
(2) Airport Capacity,
(3) Freedom of Airspace.
(4) Safety and Flight Control.
(5) Non- and Low-Capital Policies to Improve Efficiency.

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NEW ENGINEERING & DEVELOPMENT INITIATIVES -- POLICY AND TECHNOLOGY CHOICES

Consensus Views
of
User/Aviation Industry Representatives

APPENDICES

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March 1, 1979

NEW ENGINEERING & DEVELOPMENT INITIATIVES --
POLICY AND TECHNOLOGY CHOICES
APPENDICES

PARTIAL

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The users do not necessarily agree with the Appendices included in this volume, but considered them helpful in their deliberations.

NEW ENGINEERING & DEVELOPMENT INITIATIVES --
POLICY AND TECHNOLOGY CHOICES

Chapter I

APPENDICES

PRODUCTIVITY AND AUTOMATION
Topic Group 1

APPENDIX A
RELATIONSHIP OF SOME CHANGES IN COMPUTER TECHNOLOGY TO FAA AUTOMATION*

This section briefly notes the technology trends that will impact ATC automation. Both hardware and software are discussed.

Hardware

The primary technology trend that will continue to affect air traffic control system design in the next decade is the decrease in cost per unit of computer hardware resource. This cost decrease is based on innovations in semiconductor manufacturing which permit very high density packing of components on a wafer. Since manufacturing costs are dominated by the labor of packaging the wafer (and secondarily wafer size), the cost per unit function will continue to decrease. The fundamental physical limits on packing density are still some distance below the current state of the art and the next immediate innovation steps (e.g., electron beam lithography) are in the development stream.** The system implication: spend hardware to buy simplicity (i.e., ease of software development), flexibility, and growth capability.

The technology advances have affected the basic system architectures being used in industry. A primary example is the trend toward systems consisting of federated minicomputers where traditionally a large mainframe machine might have been used. In the past, the FAA requirements exceeded commercially available system capabilities and unique engineering was justified. Future system growth can now be most economically based on commercial practice.

Possible architectures for ATC computer systems range from classic mainframes to highly distributed network oriented designs. Some implications are discussed below:

(1) Large Mainframe Processors

Very healthy competition exists in the commercial data processing market that is resulting in rapid improvement in the cost/performance ratios of "traditional" large mainframe

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* This appendix was prepared by Richard W. Telsch, of The MITRE Corporation. The users considered this input as useful to their deliberations, but do not necessarily agree with or endorse the presented information.

** Concurrent innovations in bubble memory and charge coupled devices will fill a gap in the bulk memory speed hierarchy between semiconductor and electromechanical devices. This will impact system architecture as well.

machines. The original NAS 9020 design using several multiprocessing IBM 360 elements represented in part a need to configure a system with capacity beyond the typical commercial installation. Today, capacity as much as 10 times the 9020 is available in the commerical market place. Since the existing ATC systems were implemented as large integrated software systems, transferring the existing software to a new machine without complete rework might only be possible in the case of a large mainframe machine.

There are three primary cautions that would inhibit choosing this route for future ATC system growth:

(a) A mainframe system could place hard bounds on feasible growth in capacity (and limits on the granularity with which it can be tuned to the needs of individual sites). After procurement, technical innovations cannot be readily incorporated.

(b) Commercial mainframes do not normally provide for the requisite level of redundancy for the ATC application. This may require special engineering and then procurement of essentially duplexed or triplexed systems with the attendant cost penalty.

(c) Even those processors that emulate the instruction sets of the existing ATC machines will not allow zero work capture of the existing software. Code in areas such as the operating system, reconfiguration management, and hardware diagnostics would have to be redone. The software goals to be discussed below argue for rewriting of the software in any event.

(2) Distributed Processing

The availability of highly cost effective medium, mini, and micro processors is driving the industry towards distributed data processing systems. These include both hierarchical and single level systems.

A clearly dominant trend in distributed data processing systems is the move to hierarchical systems: intelligent subsystems such as "smart terminals" doing processing at the local level and communicating to a higher level processor. It seems clear that this trend will find application in the ATC system, e.g., the FAA is already planning sector position level processors to support electronic tabular displays and the radar display itself.

In the single level aspects of a distributed processing system, we see more or less coequal processors cooperating on an overall computation problem. The architectural distinction between these systems and the classic multiprocessor is that these are individual computers with their own memories rather than processor elements operating out of one common memory.*

The advantages of the distributed approaches are:

(a) The economics of the basic technology indicates the industry will continue to evolve in this direction.

(b) Capacity can be added in manageable increments.

(c) Redundancy can be provided in various degrees, including varying the depth of backup with the criticality of a given function.

(d) Potential exists for incorporating new technology in subsequent increments to the system, especially in the lower levels of the distributed hierarchy.

A disadvantage of distributed processing is the somewhat nontraditional design task of organizing data flows between machines to provide flexibility in subsequent enhancements. Also, if several different machines types are used, the problems of common software tools and development environments must be addressed.

A distributed architecture proposed for military command and control systems, and used in current avionics applications, is based on the use of a very high bandwidth bus or transmission network to tie together highly decoupled processors. In these concepts, the design interface of a given processor to the rest of the system is the logical message set being read from or written to the bus, rather than hardware or software knowledge of specific interconnections with other processors. A key aspect is that the receiving processors, through a standard bus interface device, filter the information they need from the total data flow on the bus. New sources or sinks of data can be added without disturbing the existing system.

* Hybrid systems exist. For example, the Texas Instruments' DABS architecture consists of independent processors with local memory but each processor also accesses a common global memory.

The advantage claimed for such an approach are:

(a) Additional capacity can easily be added by simply interfacing additional processors to the bus. The capacity of the system can therefore be tailored to specific site requirements.

(b) New functions can be implemented with minimum rework of the existing system.

(c) Processors, data bases, displays, etc, that incorporate new technology can be readily interfaced to the system. Only a single bus interface device must be configured to match the system standard bus technology.

(d) Functions can be implemented incrementally in procurements that include hardware and software as a unified package. Each added processor (and its software) might be a simple, low cost design since it is supporting only a single thread application program.

(e) Various degrees of redundancy and backup can be readily provided.

Since the major data flows of the ATC system are available on the bus in a unified and protected form, check out and verification of new functions can be done against operational inputs without compromising system operation.

The primary concern in evolving toward such a system would be development risk. While the basic technology of bus media (e.g., coax cable and fiber optics) and of the bus interface devices is available commercially, there is no exising large real time system using this approach. It may be possible to reduce risk by utilizing bussing concepts in a hybrid system that does not go as far as the "everything on the bus" end point.

In summary, the continuing decrease in cost/performance ratios of the hardware should result in concentration on the primary ATC system technical goals rather than on maximum utilization of the individual hardware elements. These hardware technical goals include:

(1) High degree of expandability.

(2) High degree of reliability and availability.

(3) Ability to incorporate new technology.

(4) Adoption of commercial systems to the extent possible.

(5) Provide an environment emphasizing simplicity of software and flexibility in implementing new functions.

Software

The primary assumptions are:

(1) advanced ATC automation requires very high integrity software that accomplishes high complexity processing,

(2) the industry has developed a considerable base of improved software production and verification practices as compared to the state of the art when the NAS system was designed, and

(3) the hardware economics now permit aggressive use of these new techniques.

Since software in large systems now represents as much as 80% of system life cycle costs, these factors will be highly significant in future system design.

Three areas in which advanced automation will levy new requirements are software production practices, testing and validation, and operational evaluation.

Current industrial software production practices emphasize the requirements analysis and design phase of software development since error correction is much less expensive at this stage than during coding or debugging. A recent trend is use of semi-automatic tools for maintaining and analyzing the functional specifications. Various formal requirements specification languages have been proposed, with associated tools to verify consistency and completeness of the requirements statements. Another emphasis is the ability to trace back from any design feature to the requirements statements. These languages may become a mechanism for formally specifying software to contractors in the future.

After requirements analysis, current design practice emphasizes such concepts as structured programming, top down design, stepwise refinement, highly modular coding, simple inter-task communications, and several other buzzwords. The basic emphasis is to strongly emphasize design simplicity and highly regular control flow, with explicit attention to ease of future modification, rather than "tricky" optimization of a given processing step. Efficiency should be preserved at the algorithm level, not at the expense of less understandable implementation.

The use of higher order languages (HOLS) in system implementation is no longer debatable in the industry.* The advantages of HOL in facilitating well structured design, in providing self-documentation of the algorithms actually executing on the machine, and in providing associated cross-reference and verification tools, now dominate considerations of machine efficiency. It is usually found that concentration on algorithm design yields much higher payoff than the instruction level optimization traditionally argued for hand coding in assembly language.

However, use of HOL implies careful FAA attention to control of the language and its supporting tools (libraries, verification aids, editors, loaders, etc.). It will be highly desirable to restrict FAA systems to one or a few languages that are widely available in the commercial market place and controlled under a formal standardization program. The use of common languages even across different processors in the ATC system is important for training, documentation, use of common support tools, and configuration control.

A significant current activity is the DARPA effort to develop a single common HOL, designated DOD1, for use in embedded computer systems. Assuming this effort is successful and results in widespread utilization, it should be strongly considered for FAA use.

Several approaches to reorganizing the software production process, e.g., chief programmer teams, have been proposed with varying degrees of success and ability to transfer the approach throughout the industry. One area in which consensus appears to exist is that making the individual programmer's product more public is highly effective. Design and code walkthroughs, in which reviewers assess the software in conjunction with the author, yield benefits in early detection of errors and misconceptions. This technique appears to be becoming a industry norm.

A final software production practice is the use of semiautomated program production libraries to receive the software asset as it develops and to assure configuration control. These library tools maintain the source and possibly documentation data base, control builds of new software releases, keep a continuous record of changes, and provide management statistics. An associated idea is the use of program librarian staff. The individual programmer must pass his production to the program librarian to have it incorporated in the formal project asset. The librarian is then responsible for

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* Except perhaps for extremely small microprocessor based systems. Even here, languages are being developed for this environment.

assuring the format, documentation, and test requirements on the software module have been met prior to incorporating it in the project library. The library tools should be available after procurement to support the software maintenance activity.

Future ATC automation procurements should provide the resources and encourage use of the best production disciplines available. The life cycle cost of marginal development practices dominate any front end savings.

As advanced automation forces greater reliance on the integrity of software, it will be necessary to increase the degree of testing and verification applied to new releases of software prior to operational use. Technology trends in this area include:

(1) Attention to verification requirements during basic design. Modules are configured to provide for ease of testing and validatable input/output relationships as well as meeting the functional requirements. Semi-automatic verification at the source code level of programmer inserted statement assertions is also being used to assist in securing design correctness.

(2) Semi-automatic tools for generation of test cases are being developed. These tools are based on analysis of the control flow in the software module, and attempt to generate tests that exercise every path and every decision mode in the program. When supplemented by manually derived test cases, they provide a degree of insurance that the total module has been exercised.

(3) As software integration proceeds or when a module has been modified during maintenance, it is important that the developed test sequence can be reapplied and re-validated. Test library and application tools have been developed that permit automatic application of a sequence of test cases and retrieval of previous results for comparison.

(4) A current practice is use of independent verifications and validation contractors to support these efforts, in addition to the internal efforts of the software contractor. The V&V resource should have considerable expertise and inhouse tools in these areas.

The primary new emphasis in the testing area is that test and validation should be regarded as a highly skilled, highly critical activity with a significant investment in tools and standard procedures. It should be considered as an integral part of the total software production process and carefully designed into the system from the start.

One addtional technique, which should be regarded as complementary to testing rather than competitive, is proof of correctness. Considerable academic work has been done in this area. This work attempts to take a statement of the inputs to a program and its specification and then prove in the sense of formal logic theory that the program is correct. The ultimate goal would be automatic verifiers operating on the source code and the requirements/specification statements. These techniques have been successfully applied to modest size programs (e.g., 1000 statements) and form the basis for recent work in security kernels for operating systems.

While the current state of the art does not permit proof of correctness of large, real time systems (and such a development is not imminent), it may be possible to apply some of these ideas to limited, high criticality modules of future automation systems. Also, attention to proveable assertions during design assists in insuring program integrity. This technology should be considered in developing future systems.

Even with good software production practices and a careful test and validation program, considerable operational evaluation will be necessary during introduction of advanced automation functions. The first goal of operational testing is to verify whether the functions, although operating perfectly as designed and specified, actually are acceptable in an operational environment. This has traditionally been done by bringing up a new software system during off-peak hours and then accumulating experience and recommending changes. The second goal of operational testing is to stress the software with the full range of input patterns that occur in actual use. It is impossible in the formal test program to completely anticipate the random combinations of inputs experienced during operation. In effect, software reliability of a package slowly increases as the program is corrected. As confidence in the operational suitability of the software and in its stability increases, the new function is transitioned to routine use.

In a future environment of 24 hour per day operation and highly critical software functions, it may be unacceptable to operationlly check out software using the "graveyard shift" approach. Currently, pseudo-operational testing and evaluation can be done based on simulation environments (such as the NAFEC simulators driving the NAS System Support Facility), by use of captured operational data (e.g., the System Analysis Recordings of NAS or the Extractor Tape facility of ARTS), and special simulations. It would be valuable in future systems to provide as comprehensive a facility as possibly to permit testing of new functions on operational data streams, without impacting actual ATC operations. This might involve on-line exercises in which the new system element accesses operational data

in a read-only fashion and provides outputs only to test and observer positions. It should also be possible to record the data streams for repetitive testing and analysis. Careful attention to design of this capability would be required, including both technical support and attention to the design of the testing philosophy (e.g., accounting for the fact that the real world diverges from the solution generated by the automation function under test, etc.).

APPENDIX B
THE AERA CONCEPT*

Since 1974, FAA has sponsored an R&D project in advanced ATC automation which has focused on the functions of en route traffic control. It is referred to as the Automated En Route ATC project, or AERA, for short. Its guiding design concepts are described here as an illustration of what advanced ATC automation, whether en route or terminal, might look like.

The concept assumes that ground-based ATC computers at the field facility level, whether en route or terminal, would perform most ATC functions under the active management of human air traffic controllers. Those functions would include the planning of conflict-free clearances and of metering and spacing instructions for the use of saturable runways or airspaces. Tracked DABS surveillance data would be the basis for automatically following the progress of cleared flights. The internally stored clearances and control plans would be automatically updated or revised, as required, by the progress monitoring function or other inputs. The human air traffic controllers become managers of this automated process, intervening as procedures or their judgments dictate, to control the process and to handle exceptional cases flagged for their attention by the automation system. This requires that displays of the current air traffic situation, currently stored flight plans, the computer's currently stored plan for subsequent clearances and other instructions, and other information be continuously displayed to the controller, or be made quickly available to him upon request. Alternative control modes are defined which could be involked at controller discretion to handle designated flights in special ways.

To the degree that flights are equipped to exchange messages via data link, that would be the normal mode of communication between the ground-based automation system and the participating flights. The down-link would permit equipped users to make service requests of the ATC automation system directly and to reply to up-linked messages. The up-link would carry computer-stored messages and replies to down-linked requests.

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* This appendix was prepared by Richard A. Rucker, of The MITRE Corporation. The users considered this input as useful to their deliberations, but do not necessarily agree with or endorse the presented information.

Voice radio communications would be retained for verbal negotiations between pilot and controller and to serve those users unequipped with data-link.

AERA Design Approach

The design approach used in AERA is related to the desired benefits the system is to provide.

(1) Greater Freedom of Flight Movements: By making the process of coordinating clearances internal to the automation system, and taking advantage of the computer's better predictive capabilities and potentially larger coverage of the airspace, many of the workload-related constraints now imposed on flights movements hopefully will be removable. Procedurally fixed cruising and crossing altitude restrictions should give way to dynamically generated restrictions which are imposed only when conflicting traffic is actually present. Random direct routings should be easily handled by the computer.

If pilots through airborne devices can directly query the ATC computer for the availability of more desirable routes or altitudes that are conflict-free, the ability of the pilot to improve his flight dynamically should be greatly enhanced.

Analysis suggests that many types of conflicts can be predicted by the ATC computer well in advance with a low false alarm rate; say more than 5 but less than 20 minutes before closest approach. This opens the possibility for advising the pilot of the particulars on a real conflict early. This would give him the opportunity to make small adjustments in his speed, climb rate, or courseline in a direction designed to resolve that conflict. If he responds and is successful, then there is no need for ATC intervention. If not, ATC could reserve the lead time necessary to intervene and impose on appropriate restrictions or maneuver to insure separation.

Cockpit displays which integrate traffic information and ATC clearance information can be driven by the ground-based AERA system via data link. For example, AERA could be expanded to support the use of traffic based clearances as described in the Pilot-Based ATC concept presented in Appendix D.

In general, the ability to automatically exchange data between airborne and ground-based computers in real time will make possible more refined flight planning and more efficient ATC. For the airborne flight management computer, it would now have access to the ATC data base for, say, down-course winds aloft.

For the ATC clearance planning function, it could now have access to the airborne management computer's data base for the currently planned climb or descent profile or speed schedule, gross weight, outside air temperature, etc. While such capabilities would permit improved prediction accuracies and planning efficiencies for those users so equipped, such capabilities cannot be expected to be universal. Lacking access to such data, the ATC computer would resort to pre-stored or pre-filed nominal values for prediction and more conservative separation parameters for clearing unequipped users.

(2) Greater Productivity per Controller: By delegating routine tasks to being computer-executed processes, and with the controller as the manager of those processes, it may be possible to greatly enlarge the airspace volumes assigned to individual control teams. This would permit significant reductions in the number of control teams required for any given level of traffic demand. It would also permit a significant reduction in the average control team size by reducing the number of controllers now required to perform routine support tasks associated with clearance coordination and flight data entry.

It also seems reasonable to expect that the controller's job satisfaction can be enhanced, given the relief from repetitive chores and the expanded role as a manager of the traffic control process. Questions of how to retain controller proficiency and interest in managing a largely automated process naturally arise and require supportable answers. This is another important subject for subsequent design and experimentation efforts.

(3) Fewer Traffic Control Errors: The majority of ATC system errors today are attributed to either controller inattention or poor judgment. With the processes of clearance and control instruction planning, progress monitoring and plan updating, and control communications mechanized in the computer, the problems of occasional lapses in human performance at the primary level of control may be eliminated. The job of the human controller would becomes one of evaluating the computer-generated plans and performance from the perspective of a manager, intervening as his independent judgment dictates. With the computer planning, and the controller evaluating, a level of independent quality control can be realized.

A second level of quality control can possibly be exercised by the pilots themselves, if they are equipped with CDTI displays, as pointed out in Appendix D.

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APPENDIX C
STRATEGIC CONTROL*

Today the air traffic controller uses radar to assess the traffic situation and uses speed, altitude and heading instructions to separate and space aircraft. This is a "tactical" system using relative-position separation in which the planning horizon is short and the situation is allowed to develop before solutions are offered. The pilot does his own navigation only when there are no nearby aircraft. As the flight encounters traffic of increasing density, ATC intervenes more and more until in a busy terminal area the controller is vectoring (navigating) the airplane continuously in all three dimensions and in airspeed. This control system is manpower intensive, uses relatively inefficient flight paths to solve traffic situations, and is at or near its capacity to handle traffic and support increased runway operations.

However, the ATC system is evolving toward a "strategic" type of control system in which long-term planning and time separation are used to solve the traffic situation. The application of strategic control to high-density airspace is being supported and studied by both U.S. and European investigators.[1,2,3,4] Strategic control, due to its long-term planning allows the use of efficient flight profiles to solve the traffic problem. When implemented using precise four-dimensional navigation and guidance equipment it reduces the workload on the controller by putting the navigation back in the cockpit and can increase runway capacity through more precise control of aircraft operations.

The Department of Transportation Advanced Air Traffic Management System (AATMS) Study defined an ATC system concept to accommodate air traffic growth projected for the 1990 time frame.[5] The system concept includes a strategic control system in which ATC determines nonconflicting four-dimensional flight paths for all aircraft under positive control, and the pilot executes the clearance by accurately flying the assigned four-dimensional path.

The four-dimensional path consists of a series of waypoints defining the flight route with altitudes and times assigned to the waypoints such that the vertical profile and speeds are defined along the entire route. Spacing adjustment is accomplished by controlling aircraft speed along track rather than by path stretching.

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* This appendix was prepared by Ralph L. Erwin and James T. Burghart, of Boeing Commercial Aircraft Company. The users considered this input as useful to their deliberations, but do not necessarily agree with or endorse the presented information.

Strategic control consists of the two basic functions of planning the flight path and then executing it. The logic for strategic control of arrivals has been investigated in some detail.[6] The first step of this logic is to determine the sequence in which the flights will be scheduled. In the simplest concept they are sequenced by first come - first served to the runway. As each flight reports in, its potential arrival time at the runway threshold is calculated for efficient flight along a nominal path. The aircraft are then sequenced by time ordering these estimated landing times.

Next a scheduler computes an assigned landing time for each flight which reflects other traffic and is the first available time at or after the estimated time. The scheduler is designed for efficient runway utilization by considering the appropriate time or distance separation between operations and the procedure for mixing departures with arrivals.

The scheduled landing time is the basis for computing the four-dimensional (4D) path from the aircrafts' present position to the runway. This path completely defines the airplane horizontal position and altitude as a function of time. The 4D paths are tested to insure that the paths for different flights will not bring the aircraft into conflict.

The preferred method of controlling the flight to maintain the scheduled 4D path, is to provide the scheduled 4D path to the aircraft and allow the pilot to use precision 4D navigation/guidance equipment to fly the path.

Using the airborne control loop, the aircraft navigation system obtains the position data which is compared in the guidance system to the ATC-provided 4D path. Speed and steering signals, which will null out any errors, are generated and sent to the flight control system. ATC uses the radar for surveillance and for vectoring any unequipped aircraft.

This airborne control system has several advantages which indicate that it is the preferred technique.

(1) The navigation update rate exceeds that of the radar and precise control can be expected.

(2) The pilot is in command of the flight and where it is going. For example, if the assigned path would take the aircraft into unacceptable weather he will know it and can negotiate a safer path.

(3) In case of an ATC or communication system failure, the pilot knows the expected 4D path and can continue the flight.

When considering the control loop it must be recognized that the concept does not preclude airborne devices such as the Beacon Collision Avoidance System (BCAS) and the Cockpit Displayed Traffic Information (CDTI) System. These are airborne surveillance systems for checking on ATC operations (and how well pilots are adhering to clearances), and will work in conjunction with strategic control just like the ground ATC surveillance function.

The required precision four-dimensional navigation/guidance technology is available. The NASA has two separate systems which have demonstrated the necessary capability. At Langley Research Center, the Terminal Configured Vehicle (TCV) program has a 4D system installed in a B-737 airplane; while at Ames Research Center the STOLAND 4D navigation system has been tested in a CV-340.

In the NASA B-737, the avionics configuration which has produced the best results consists of a general purpose digital computer for navigation and guidance calculation, an inertial navigation system, and dual DME inputs.[7] Performance in the along-track direction is of primary interest to strategic control. This performance can be represented by two errors: (1) the flight technical error which is the ability of the airplane to maintain the navigation-system desired position and (2) the error in the navigation system calculated position. NASA test results on two flights produced total along-track mean errors of 709.8 meters (1074.2 meters one-sigma) and 252.4 meters (123.5 meters one-sigma).

The NASA (Ames) STOLAND avionics also uses a general-purpose digital computer for navigation and guidance. Flight testing has been accomplished using position data derived from ground-based navaids (TACAN and the MODILS scanning mode MLS) and onboard body axis accelerations.[8] Based on 27 flights in the CV-340, the Time of Arrival errors at a point 2 miles from touchdown were $\pm$ 5.14 seconds (two-sigma).

The larger along-track flight-technical errors have resulted from the accelerations required when turning in a significant wind environment. Near the airport, this situation will not normally be present and flight will be more precise. In a strategic control system an accuracy of 2 to 3 seconds (one-sigma) is required at the arrival gate for precise delivery to the runway to maximize runway capacity; however, farther out a somewhat larger error may suffice for safe along-track separation.

Boeing flight tests of the NASA B-737 produced outer-marker flight technical errors of under one-second. This performance is coupled with navigation using precision DME on the airfield; the accuracy planned for the Microwave Landing System is expected to produce the required delivery accuracies.

The Federal Aviation Administration (FAA) now has operational in the field a method of time-based metering of arrivals which can be the beginning of strategic control.(9) Relatively simple calculations are used to estimate the time each arrival should pass a metering fix so that it can fly directly to the runway and land without delay. These calculations are done while the aircraft are still at cruise altitude so any necessary delay can be absorbed at higher altitudes where jets operate more efficiently. Although, the system is initially manually implemented and uses vectoring to achieve the metering fix times, significant operational improvements have been reported. The terminal area peak traffic count and arrival controller workload are reduced and aircraft are saving fuel by avoiding excessive low-altitude vectoring.

The evolution of time-based metering to include the use of aircraft performance and wind data in defining the best four-dimensional path to the metering fix and the use of four-dimensional navigation equipment to fly to the metering fix will complete the en route portion of strategic arrival control.

A data link such as planned for the Discrete Address Beacon System (DABS) is desired for effective transfer of data such as complex four-dimensional paths and wind data. More important is the integration of airborne four-dimensional navigation equipment to fly the four-dimensional paths.

The operational advantages of strategic control holds the potential for benefits for all elements of the air transportation system, most directly for the airplane and ATC system operator.

Airfield capacity may be increased because:

(1) The use of 4D navigation will relieve the controller of his vectoring workload and associated communications task and essentially remove the controller as a constraint on traffic flow and,

(2) The precise delivery of aircraft to the runway will minimize the buffer required for spacing errors and allow operations closer together. Today, with wake turbulence as a constraint, a 10 to 15 percent increase in IFR runway acceptance

rate can be expected. However, the Wake Vortex Avoidance System (WVAS) is expected to allow separations as low as 2 nmi; which will strategic control can increase the IFR acceptance rate another 40 percent. With no wake turbulence constraints the ultimate IFR acceptance rate is about 90 operations per hour.

The operator may also achieve significant fuel saving benefits due to both the use of more efficient flight paths and reduced delay. With proper planning several minutes of delay can be absorbed (within 175 nmi of the airport) during the final few miles of cruise and descent, rather than in a holding pattern or by path stretching.

When a flight must absorb delay waiting for the first available runway landing interval, the minimum-fuel strategy is to absorb as much time as possible by slowing down using an idle descent.(10) If more time must be absorbed, cruise speed should be reduced to long range cruise. Note that when the landing time is fixed, minimum fuel is essentially minimum cost.

Strategic control can schedule arrivals to the runway based on these idle descents. Even in the no delay case this will save fuel. Studies have shown savings (from present practices) of over 500 pounds of fuel possible using idle descent speed schedules that represent good compromises between time and fuel. In cases where delay must be absorbed additional savings can be obtained. Actual savings depend on the amount of time to be absorbed and the assumed alternate delay absorption method. For a three minute delay a 727-200 would burn 600 pounds of fuel less using an idle descent speed schedule instead of path stretching.

There are also potential safety benefits. First, since each flight knows the precise 4D path it is expected to fly, should communication be lost with one or more aircraft, flights can continue without conflict. In addition, increased safety is implied by the dissimilar redundancy of controlling the airplane with on-board navigation/guidance equipment while providing surveillance by ground-based secondary radar. If there is a navigation or surveillance system error, the difference will signal that something is wrong and safe actions can be taken until the error source is found and corrected. Similarly, if navigation fails the airplane can be vectored from the ground, while if the radar fails control can be continued using data-linked navigation position data.

In summary; the technology is available for aircraft to fly a system of assigned time slots such that many of the problems of todays traffic control will be overcome and both the aircraft and ATC system operators will benefit substantially. The evolution to strategic control depends upon allocating the system components

between the air and ground elements so optimum system operations are obtained. Specifically, the system should be designed to use precision airborne four-dimensional navigation guidance equipment.

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APPENDIX D
PILOT-BASED ATC CONCEPT*

1. BASIC CONCEPT

This concept for providing opportunity for greater pilot involvement in the ATC process is one which is based on, and is consistent with the current ATC system. The approach is to augment the current type of ATC services with a special set of beneficial clearances, which are provided to operators who choose to purchase special avionics and who choose to take on greater ATC responsibility with regard to their own aircraft. These special clearances may provide the operator with opportunities for improving his flight's efficiency in terms of reducing flight time, and may provide him with more freedom in using the available air space. There are potential safety benefits as well. Finally, if a large enought set of operators choose to equip, it can be postulated that potentials exist for increasing airport capacity, improving ground operations and reducing the ratio of air traffic controllers to flights. This concept was devised to provide a vehicle for discussion and to serve as a model in which a system and scenario is defined. This model can now be examined in technical detail for feasibility, validity, and value.

1.1 Avionics

For this concept, the set of avionics required to provide an operator with the greatest opportunities for involvement in the ATC process consists of:

(1) Area Navigation Computer (with stored airway and airport maps).

(2) Weather Radar

(3) Data link receiver

(4) Integrated traffic and ATC information display

- (a) navigation map (RNAV)
- (b) weather information (weather radar)
- (c) traffic information (data link or on-board sensor)
- (d) ATC information (data link)

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* This appendix was prepared by the Pilot-Based Subgroup, William Cotton, of ALPA, chairman. The users considered this input as useful to their deliberations, but do not necessarily agree with or endorse the presented information.

(5) Collision Avoidance System (either air derived or provided from the ground via data link, assuming duplicate ground coverage).

In order for an operator carrying this set of equipment to be able to receive the fullest opportunity to involve himself in the ATC process in a given airspace, all other aircraft in the airspace in question must carry a transponder and an altitude encoder. Some of the airspace already requires this equipment. If the proposed system is adopted, most of the airspace used by air carrier airplanes will require Mode C transponders.

2. ATC PROCESS

The ATC process can be divided into several components. The following division is used to discuss the proposed concept for more pilot involvement.

(1) Flight Planning
(2) Taxi Out
(3) Departure (including climb)
(4) Cruise (including cruise-climb)
(5) Approach (from top of descent)
(6) Final Spacing
(7) Taxi In

Each of these will be discussed in turn, with attention paid to the role of the operators who choose to carry special equipment, the role of the operators who do not, and the role of the ground system and the air traffic controllers.

2.1 Flight Planning

The proposed concept has no special requirements in this area relative to other concepts. This concept would be looking towards improvements in today's system, consistent with the use of an RNAV system as part of the special avionics set. The future system must be better equipped to permit random routes, and also be less restricting in terms of available altitudes. These limitations can be corrected by means of adding ground-based automation capabilities to the en route system similar to those described in the AERA (Automated En Route ATC) concept in Appendix B. Thus, independent of which ATC concepts are pursued, the need exists to develop computer aided capabilities which eliminate current non-traffic related ATC limitations in using airspace.

2.2 Taxi Out (Or Taxi In)

2.2.1 ATC System Responsibilities for All Aircraft

Independent of whether or not an aircraft is operating with the special avionics set, the ATC system on the ground will be responsible for:

(1) Selecting its departure runway subject to the operator's approval.

(2) Determining desired taxi routing.

(3) Determining where taxiway conflicts with other aircraft can occur, and establishing which aircraft should yield the right of way to avoid a conflict.

This set of responsibilities is consistent with what the ATC system does today. The change to today's system would be in the use of traffic related clearances and in the responsibilities for execution of certain taxi clearances. These are discussed below.

2.2.2 Responsibilities of the Specially Equipped Aircraft Operator

The operator carrying the special avionics, when ready, would receive via voice and/or his data link a taxi clearance which would cover as much of his taxi operation as possible, (i.e., if possible from the gate to the departure runway queue). For example, this clearance might read, "TWA 7 cleared to taxi to Runway 14, via taxiway C. Proceed direct to the intersection of B&C, provide right-of-way to AA 115 at the B&C intersection and the proceed to follow AA 115 to the Runway 14 departure queue." In some cases the taxiing process may be so long in duration and include so many interactions as to make derivation of the entire clearance impractical. In these cases, the ATC system would update and send the additional parts of the clearance as they are derived. This clearance would be continuously displayed to the pilot (and modified when necessary) so as to minimize the possibility of the pilot making an error relative to the intended ATC actions required of him.

Prior to taxiing, the pilot would set his display to the taxi position, and his display would show him a previously stored taxiway map of the airport, with his own aircraft in its appropriate position on the map (derived on board or ground derived and sent via data link). In addition, other pertinent traffic identifications and positions (derived on board or

ground derived and sent via data link) would be presented on the display. This display would be updated regularly to account for aircraft movements. Finally, the pilot would have a presentation of his own aircraft's course position relative to the taxiway center (ground derived and sent via data link or derived on-board) and relative to upcoming turn points. These types of information would be used for navigation purposes when visibility requires its use.

Using the above information, the pilot is able to:

(1) Double-check the validity of his own clearance from a safety viewpoint, by use of the traffic information or visual siting, depending on weather.

(2) Carry out his clearance, using either his traffic information or direct visual sighting (depending on weather) for spacing and providing the ATC system's established right-of-way.

(3) Navigate along the taxiway using visual and cross-course position information, depending on the weather situation.

2.2.3 Responsibilities of the Unequipped Operator

The unequipped operator (but equipped with transponder where special procedures are applied) receives his taxi-out clearance from ATC and, when visibility permits, he double-checks the clearance validity based on visual sighting. Weather permitting, he follows his clearance, yielding right-or-way as required using visual sighting for spacing and yielding. In poor visibility situations the ATC system provides tactical instructions to provide right-of-way (stop, start instructions), and to provide spacing. The ATC system may give navigation aid to the pilot unfamiliar with the aircraft to get his aircraft to its objective point if the tower can see or has sufficient position information on the aircraft.

2.2.4 Reduced Responsibilities of the Air Traffic Controller for Productivity Increase in IMC

The air traffic controller in this concept would carry out the same role he would in an automation concept for aircraft without special avionics. However, for specially equipped aircraft three key functions would become primarily the operator's responsibility in all weather, namely:

(1) Maintaining taxi separation while taxiing his aircraft.
(2) Taxiway navigation in poor visibility.
(3) Holding at intersections for a taxiway to clear.

Since the controller already plans for these functions to be the operators' visibility when permits, it is clear that it should help him carry out the other parts of his job (related to the items in 2.2.1 and unequipped aircraft) in poor weather situations. The controller would rely on the pilot of a specially equipped aircraft to initiate the proper stops, starts and turns in conformance with his clearance as he does in present VMC. In unusual cases where errors occur, the controller would coordinate the response to these errors with the pilot. This coordination could be substantially aided by automation through early detection, notice and situation resolution. For example runway-taxiway intersections would be monitored for conflicts.

2.3 Departure Procedures

2.3.1 Responsibilities of the ATC System for All Aircraft

The ATC system would be responsible for clearing aircraft to depart the Terminal Area and for defining the departure routing. However, the process for establishing the optimum terminal departure route would be automated, and would include the conducting of a series of conflict and weather probes along a successively less desirable choice of routing, until an acceptable route is derived. The route definition may include the need for using altitude constraints as well as route parameters to have aircraft avoid each other, and in conflict cases the ATC system would determine which aircraft should yield the right-of-way, or be moved from its most desired route.

An important new idea in the concept presented here is that the criterion for acceptable routing is different for specially equipped aircraft than it is for unequipped aircraft. This becomes evident in the following paragraphs.

2.3.2 Responsibilities for Specially Equipped Aircraft Operator

The operator of specially equipped aircraft will receive, via data link, one of two types of departure route clearances:

(1) Specific conflict free clearance, to be navigated, e.g., "Cleared direct to ABC. Cross ABC at 18,000 feet." In this type of situation the RNAV system would be used to

navigate the cleared route and the traffic information would be used to double-check the safety of the clearance and to monitor own flight's safety.

(2) Specific single conflict clearance to be navigated, e.g., "Cleared direct to ABC, climb and maintain FL 180, cross ABS at 18000 feet, give way to AA-15 crossing at 2 o'clock, 16 miles prior to ABC at 13000 feet." This is a new type of clearance, which would only be issued when the separation action taken by the equipped aircraft could not interfere with any other traffic, i.e., no third aircraft is nearby when this clearance is used. The thus designated burdened pilot would be required to separate himself by an established separation standard, such as 3 nmi or 1,000 feet. The information needed by the pilot with regard to the intent of the aircraft he would separate himself from would be provided from the ground system via data link. In a case involving two specially equipped aircraft, the aircraft which is provided right-of-way could be told that the other aircraft is yielding the right-of-way to him, e.g., "Climb and maintain 18000 feet, cleared direct to ABC. Cross ABC at FL 180 feet. NE 351 crossing at 10 o'clock 16 mi prior to ABC will give way to you". The cleared operator can then use his traffic information in verifying clearance and observing other aircraft maneuvers for the safe passage. This type of clearance will be referred to as a "contracted clearance." The assumption behind this concept is that a pilot will be able to perform the function of clearing a single aircraft conflict without causing another conflict or clearance alteration. In addition, many anticipated conflicts would not even require what would be considered as a maneuver, since the prediction process accounts for a range of possible aircraft performance, which in any particular case the pilot can control to avoid a conflict, e.g., in a given case the prediction process may assume a 4° - 8° range for climb angle, and if the upper part of this range creates a conflict the pilot can use 4° to avoid the conflict and not even be considered as maneuvering.

The Collision Avoidance System, either ground derived (i.e., ATARS) or air-derived (i.e., BCAS) depending on surveillance coverage, would serve as a backup in any of the above situations and would only alarm in abnormally close passage situations which appear to be a collision threat. The pilot in this case would immediately follow their avoidance instruction.

2.3.3 Responsibilities of Unequipped Aircraft Operator

As today's system attempts to do, this operator would be issued the conflict free clearance which provides the best routing possible. The likelihood of receiving the desired routing may be greater in the future with automation, due to its ability to conduct a conflict probe for determining the best route. The pilot may have to receive navigation aid via radar vectoring as he does today when he is not equipped to execute the required navigation function. A major difference in the future ATC process to this operator is that his separation from a specially equipped aircraft may be planned and accomplished by the other aircraft's pilot rather than the ground system as under visual separation today. However, not very much else changes with regard to his departure procedures, and his interface is still with the ground controller as now, and not with the equipped aircraft.

2.3.4 Reduced Responsibilities of the Air Traffic Controller

The controller's responsibilities in dealing with unequipped aircraft would be the same as in an automation concept which has no special pilot-based procedures. However, in the case of an aircraft carrying special avionics, the controller would be relieved of two functions, namely:

(1) Navigation via radar vectoring because of RNAV systems availability on-board the aircraft.

(2) Monitoring the flight for safety purposes after issuing a traffic related clearance would not be required since the pilot could use his traffic information for these functions and would have a collision avoidance system to back him up. The controller, in the contracted clearance, would still be expected to observe and supply traffic advisories as workload permits as he does for VFR aircraft today.

2.4 En Route Cruise Procedure

2.4.1 Responsibilities of the ATC System for All Aircraft

The ATC system would be responsible for clearing aircraft on to their flight planned route. Via automation, the system would, on a regular basis, check to see if the flight plan is conflict free over the next several minutes. If not, the system would propose which aircraft gets right of way, and issue appropriate (burdened) pilot a new clearance with controller approval. The new idea in the pilot-based concept is that a new type of clearance is proposed for specially equipped aircraft. This

clearance would be a single conflict clearance, as described in the section on Departure Procedures. It would provide the pilot with the clearance responsibility which he may then provide for by staying on his existing flight plan and avoiding single identified conflicts on his own or by requesting a change in his flight plan. the pilot would deviate from the clearance only to the extent necessary to resolve the conflict under the traffic-related clearance.

The ATC system would also respond to pilot requests for flight plan changes, which for aircraft with the data link capability could be a pilot-data link-ground computer controller data link-pilot function and minimize the requirement for human interaction on the ground. Pilots with special avionics would be able to use the combined set of weather, map and traffic information to derive flight plan change requests which would have a high probability of acceptance.

2.4.2 Responsibilities of Specially Equipped Aircraft Operator

The specially equipped aircraft operator would navigate along random routes if he desired, and would receive conflict free or single conflict clearance modifications, as required. In the single conflict clearance case the pilot would be required, based on his traffic information and on additional ATC information on the aircraft's intent, to separate by a minimum separation standard (i.e., 5 nmi, 1000 feet etc.) depending on the encounter. The operator would have his collision avoidance system as a backup. In addition, the operator would use his traffic information to double-check the validity, with regard to safety, of his ATC clearances. The operator would also use the combined set of his flight information (including traffic, navigation and weather data) to determine whether, at anytime it would be desirable for him to request a modification in his flight plan. If so, via his data link, he could enter his desires onto his cockpit display, have them sent to the ground-computer for analysis for subsequent approval by the controller and transmission from the ground via his data link for execution.

2.4.3 Unequipped Aircraft Operator

The unequipped aircraft operator, would receive conflict free clearances which would attempt to best accommodate his flight desires. To this operator, this concept for automation relative to the AERA concept described in Appendix B provides one new factor which will concern his flight. This is that he must accept the fact that specially equipped aircraft may use ground

approved pilot based separation to avoid his aircraft rather than the ground vectoring system now being responsible for controlling this separation.

2.4.4 Reduced Responsibilities of the Air Traffic Controller

The role of the controller for unequipped aircraft would be the same in this concept as in normal or proposed automation concepts, such as AERA. However, continuing observation of flight progress during pilot-based conflict resolution would not be required for specially equipped aircraft. It is important to note that the reduction of flight monitoring is also an objective of the AERA concept.

2.5 Arrival Procedures (From Top of Descent)

2.5.1 Responsibilities of the ATC System for All Aircraft

As in today's system, in the proposed concept the ATC system will be responsible for selecting the landing runway for each aircraft, deriving a landing sequence and determining the delays, if any, required for each aircraft. With the use of automation this process would be time based, and each aircraft would have a desired landing time computed for it while fairly distant from the airport. If large delays are subsequently required holding patterns would be set up and managed by the ATC system, at about 50 nmi from the airport. These holding patterns would always be managed so that aircraft were cleared to leave them early (say 5 minutes) to assure that demand would always slightly exceed capacity. This would provide assurance that errors in prediction do not cause loss of potential capacity. The arrival routing would not necessarily be grouped into a given standard set (e.g., 4 feeder fixes with routes leading to the runway), but would be independently derived to maximize efficiency for each aircraft on an individual basis. In periods of very heavy arrival traffic, the use of standard feeder fixes and standard routing may be used if it improve the overall traffic control capabilities.

2.5.2 Responsibilities of Specially Equipped Aircraft Operator

As indicated above, the ATC system with automation would derive the most efficient conflict free or single conflict routing from the top of descent to landing for the aircraft. This route would be transmitted to the pilot via voice and/or data link. As in the previous discussions, in the single conflict case the pilot would be informed of the conflict and would be required to separate himself by established minimums.

The pilot would use his RNAV equipment to navigate the desired route and his traffic information to avoid the pointed out conflict. His traffic information would also be used to monitor the validity in terms of safety of his clearance. In this light traffic period, it may be that two aircraft happen to arrive in close enough time coincidence that they will arrive at the runway in some relatively close proximity of each other (e.g., within 10 nmi). In this case, and if the pilot of an equipped aircraft would be designated as second to land, he will be informed of this fact (via data link) and will use his traffic information to follow the other aircraft. If these aircraft are on a common route this following procedure may persist for a long time; if they are arriving from different directions this process may be initiated by the controller at varying distances from the airport depending on similarity or differences in aircraft performance. As described above, in heavy traffic periods the ATC system may clear the equipped aircraft via standard routing to a terminal area feeder fix where he may or may not be held. In either case, once past the feeder fix the pilot would be presented, via voice and/or data link, with a new set of information on his display related to the sequencing and final spacing process. The displayed information could include:

(1) Time box indicating where he should be now, in terms of along course progress, if he were on time. Thus, if the aircraft needs a delay (for example, he had been cleared from the holding pattern a minute earlier than his desired landing time required) the box would appear behind his aircraft's position. The waypoint times selected (which govern time box progression) will be updated as needed by the ground system.

(2) Sequence number to land and the sequence numbers of other arrival aircraft presented on his display and going to the same runway. This information is needed for recognizing when a passing situation exists. The sequence numbers may be changed by the ground system as each arrival clears the runway or when deviations from the plan occur.

Using this information the pilot would be required to adjust his flight's speed or path so that his aircraft is in the time box by the time he arrives at the final approach merge point. The pilot will use what he believes to be the most efficient delay mechanism available to him, and will be required to use his traffic information to avoid violating separation standards with any nearby aircraft he is cleared to interace with. (Note, that the use of a fixed set of arrival routes, separated from departure routes limits the situations which will give rise to

nearby aircraft which must be avoided. In fact, this should only occur in cases where passing is required due to a large speed differential between arriving aircraft on a common route. In these situations altitude separation may be used, based on specific altitude clearances derived and issued by the ATC system.)

When the pilot is in a position to observe on his display and follow the aircraft designated to land in front of him, his control mode would change from staying in the time box to following the preceeding aircraft to land. If required, the ATC system would send via data link any additional information needed about the aircraft to be followed. The assumption here is that the pilot can space himself more precisely and with less communications than the controller can, and will be more aware of his position due to reduced control loop time lag and continuous control of the aircraft.. This would provide potential for increased airport capacity and perhaps safely reducing separation standards.

2.5.3 Responsibilities of the Unequipped Operator

The unequipped operator's responsibilities would be the same as in today's system. He would receive the best routing possible and when required he would receive navigation aid via radar vectors. When large delays are necessary he could be held; small delays would be accomplished via radar vectors and speed control. In VMC, near the final approach course he would be cleared to follow and space himself behind a designated aircraft.

2.5.4 Reduced Responsibilities of the Air Traffic Controller

For unequipped aircraft the controller would have the same responsibilities as in a less pilot based concept. In medium or heavy traffic situations he would control the unequipped aircraft via automation which would provide time synchronization between the unequipped and equipped aircraft. This is, the controller would have the equivalent of a time box or other predicted information which he would use to issue correction commands to aircraft which would result in compatible performance with the time boxes for equipped aircraft.

The controller would not be required to provide navigation aid, issue delay causing commands or be responsible for compliance of equipped aircraft in this process. The Collision Avoidance System (ATARS or BCAS) on-board the equipped aircraft would serve as the pilot's backup.

APPENDIX E
SOFTWARE VERIFICATION*

1. Background

Before discussing sources of software errors and possible mechanisms for their prevention and detection it is appropriate to review the history of the evolving NAS En Route Air Traffic Control System. An understanding of the problems encountered and solved during this evolution will allow future systems to benefit from the lessons learned in system operation philosophy, program architecture and program design.

In the late 1960's the Model 1 System was built as a prototype for NAFEC and for installation at the first-article site, Jacksonville. In addition to significant differences in peripheral equipments, the Model 1 software evolved through many versions before arriving at the functional capabilities required for field operations. A great deal was learned about the problems of automating the field air traffic control requirements and about system behavior in actual field operation as opposed to the laboratory environment.
Model 1 was built as an all in-core system. This contraint and the desire for the smallest possible core storage requirement, dictated fundamental design policies:

- Code packaging to be as tight as practical
- No code or data to be duplicated
- Maximum use of Pool'ed storage
- No internal data movement.

Although Model 1 supported only a single field site, it became evident that the need to be responsive to changing requirements was of extreme importance and that a tightly packaged system was not ideal in this regard. It was further evident that both code packaging and other single-faceted definitions of "efficiency" were inadequate in that they could reduce the parallelism inherent in both the application itself and the 9020 hardware. Thus, something that appeared to be simple, efficient, low-overhead code could actually be detrimental to overall system efficiency and response time.

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* This appendix was prepared by International Business Machine Corporation. The users considered this input as useful to their deliberations, but do not necessarily agree with or endorse the presented information.

With the advent of the Model 2 Systems, the field experience gained in Model 1 was applied in the new Model 2 design. Model 2 systems were limited to Flight Data Processing functions only and the storage constraints for deployable systems were somewhat relaxed. The overall parallelism of the Model 1 architecture (both) hardware and software) had been modeled and measured, and several Model 2 design objectives were established:

(1) Increased modularity for increased parallelism and reduced module size.

(2) Elimination of duplicate code/logic which had crept into Model 1 during its evolution.

(3) Increased parallelism and reduced interference through ENTRY-LOCKing techniques and table restructuring resulting from Model 1 experiments.

(4) A retreat from use of Pooled storage for every possible use and dedication of relatively small amounts of storage to achieve other significant benefits.

(5) Improved understandability and maintainability and, therefore, responsiveness to future requirements changes.

The last objective was established knowing that these systems were to be deployed to many sites, and the maintenance and evolution problems were anticipated to be even greater than in Model 1.

From a system design viewpoint, the above objectives were achieved; however, the need for changes exceeded expectations. The initial functional capabilities provided in Model 2 required many significant modifications and additions during its period of introduction. The legitimate needs for variations in capability from site to site were simply not anticipated and with introduction at each successive site, new or different needs would surface. The Model 1 change experience with one site simply did not prepare the specification writers or the program designers for this task. The effort was ultimately successful, and the Model 2 deployment was sufficiently broad so that a great deal of experience and understanding was developed concerning the functions and areas of the program which were most susceptible to change. The basic Model 3 program architecture reflects the experience of the Model 1 and Model 2 Systems.

As the requirements for the National Flight Data Processing System (now known as A3cO) were being defined in 1970, software designers were at work defining a new program architecture within which the

Model 3 System could efficiently evolve. Efficiency, storage, and response times were major objectives; however, they could not exclude consideration of the previous field experience, demonstrating need for requirements change, maintainability, and understandability. Many tradeoffs were required and consciously made. Storage and CPU objectives were set, accepted, and achieved. The evolution of the system from A3c0 through A3d2.5 demonstrates the flexibility inherent in the Model 3 Program architecture.

An example of this evolution is the use of the disk storage facility. At the time the Model 3 architecture was being developed, the question of deploying disks in NAS was still under consideration. Although official direction to consider the use of disks in the basic architecture could not be provided at that time, the designers did not ignore the strong probability that disks would become a part of the NAS equipment baseline in the future.

In 1971, during the production of the A3c0 System, the decision to deploy disks in the NAS En Route System was made. Because the A3c0 System was to be installed in the field before disks could be deployed at all sites, only minimal use could be made of the new device. Additionally, a capability was required which allowed system residence to be either on tape or disk.

In Model 3d1.0, when disk deployment was completed, the recovery recording file was transferred to disk. In A3d.1.1, program modules were buffered fom disk. Model A3d2.0 used disk for improved bulk flight plan processing and as a storage medium for route records of proposed flight plans. In A3d2.1, the Stereo Flight Plan data base was moved from core storage to disk, and A3d2.2 buffers essentially the entire flight plan data base in addition to the disk usage previously described. Thus, Model 3 as it exists today is not an all in-core system nor a system which has been forced-fit to disk residence. The migration to disk was planned, has not caused disruption, and has been successful.

The FAA's experience in producing these systems should provide valuable insight which can be applied to future systems. While the remainder of this discussion will concentrate on software defects, their causes, and possible remedies it is important to keep in mind that future development efforts can build upon the FAA's prior experience with en route automation.

2. Applying Newer Technologies to Software Production

Until we are able to produce error free systems we must be pre-occupied with understanding software failures and the errors that cause them before we are able to establish an effective quality

assurance program. Software errors can be grouped into four basic categories which span the software development activity and its end products: fuctional specification, logic specification, code, and documentation. Published data by IBM Corporation (Figure 1) shows that data collected over several years encompassing a number of DoD programs indicates that the first two categories, functional and logic specifications, account for 60% of the life cycle defects. These two specifications in combination represent system design and a similar distribution is noted in other published data (Figure 2).

With an understanding of the cost and disruptive influence software errors cause it seem evident that failure FAA quality assurance programs should stress the goal of prevention and early detection of errors.

For each of the four software error categories discussed earlier, Figure 3 lists some of the error preventive techniques which are gaining widespread use. Application of these and other techniques has shown a reduction in the error rate from 55 to 28 errors per thousand source lines of code (Figure 4).

Until we are able to produce code containing no defects we must stress ways in which errors may be detected. A list of detection processes used in producing some systems for the Federal Government is as follows.

- Function Spec Review
- Logic Spec Review
- High Level Design Inspection
- Detailed Design Inspection
- Detailed Code Inspection
- Unit Test (Module)
- Integration Test (Subprogram Function)
- System Test (Program)
- Operability Demonstration
- Reliability Demonstration

Again while error data statistics on the FAA En Route NAS are not readily available we can speculate that if some of the newer and more promising techniques, such as vigorous design and code inspections, were applied to FAA software significant decreases in errors could be experienced. Since traditional test techniques, such as those used in en route NAS, remove only approximately 50% of the life cycle defects we can see that additional techniques suggested above hold the promise of reducing latent defects and without their rigorous, consistent application we can expect no significant decline in software errors.

Category	% Life Cycle Defect
Functional Specs	30
Logic Specs	30
Code	24
Documentation	16
	100

FIGURE 1

ERROR DISTRIBUTIONS

	Design (%)	Coding (%)	Source
TRW	64	36	IEEE Transactions
Nippon Electric	60	40	IEEE Transactions
MITRE Corp	50	50	MITRE Report # MTR-5257

FIGURE 2

ERROR DISTRIBUTION COMPARISONS

Category	Cause	Preventive Technique
Functional Specification	• Qualitative, Narrative	• Qualify Functional Parameters
	• Assumptions Not Verified	• Stepwise Refinement Process
	• No Numerical Allocation	• Contract for Operability/ Reliability Demonstration with Sepcified Failure Criteria
	• Environmental Conditions	• Develop Error Handling Design Based on Mission Profile
Logic Specification	• Complexity	• Hierarchical Program Structure/ Top Down Development
	• Abstract Design Description	• Program Design Language
	• Unproven Design Technique	• Design Standards at Module, Function and Program Design Levels
	• System Resource Control	• Lead Programmer Allocates Memory, Processor Timing I/O with Reserve
Code	• Complexity	• High Order Language/Structured Programming
	• Programmer - Discipline - Experience - Competence - Time (Schedule)	• Management Control - Quality Assurance Checks - Programmer Teams - Training - Development Plan Based On Productivity Rates - Interactive Development Facility - Programming Support Library
	• Defective Tools and Procedures	• Certification, QA Control of Support Programs, Procedures
Documentation	• Inadequate Standard	• Adopt Software Development Standards
	• Inadequate Training	• User Personnel Conduct Operability Demonstrations

FIGURE 3
CORRECTIVE ACTION: ERROR PREVENTION

Category	Life Cycle Defects/KSLOC* Previous	Current
Functional Specs	17	13
Logic Specs	17	6
Code	13	6
Documentation	8	4
	55	28

* 10^3 Source Lines of Code

FIGURE 4

ERROR DISTRIBUTION WITH PREVENTION MEASURES

Another way of viewing the problem of software defects is to examine the trend which had developed by contrasting the old style of development with modern practice as follows:

	Defects/Thousand Source Lines Life Cycle	Operational Phase
• Old Style - Bottom Up Design - Code Unstructured - No defect removal prior to unit test - Regular test cycle	50-60	15-18
• Modern Practice - Top down design - Structured Code - Full design reviews and inspections - Top down test and integration	20-40	2-4

There is every reason to believe that these same dramatic improvements can be achieved on en route software if these techniques are rigorously implemented. Careful and thorough data collection along the way is necessary to monitor progress and ascertain the results of each step.

Since the NAS En Route System is so large and system reliability is so important implementation of the above techniques is not the only answer to achieving more error free code. Computer assisted or fully automated testing techniques would make the time consuming and error prone test phase more reliable, repeatable, and shorter.

While the FAA currently employs simulation and data reduction techniques extensively during the latter stages of full system test prior to filed operation, other techniques could be employed at earlier test stages. The first and lowest level of testing, unit testing, is normally a manual effort. It might, for example, be useful to consider an automation aid which would record the thoroughness with which this testing is conducted by automatically recording, during program test execution, data which not only identifies all program branches executed but counts the number of times each branch is executed. Since this data is currently not available automation would be extremely useful in providing data to evaluate the thoroughness of unit testing.

During the latter testing phases of each NAS functional upgrade the software is exposed to thousands of unique variations of test data, resulting in tens of thousands of pages of test data output. While this data is formatted by a sophisticated data reduction system the entire process is extremely time consuming and error prone. Portions of this test analysis phase are candidates for further automation since all elements of the process (test data, expected results, and actual results) are stored on magnetic tape and disk. By changing the format of expected test results into a format more compatible with automated analysis portions of this process could be accomplished by data reduction software.

3. Recommendations

Based on the above considerations several recommendations are provided for increasing the quality of en route software as follows:

- evaluating past efforts - the design and implementation of future ATC systems should be undertaken with an eye toward results achieved in the past. Future design, therefore, should retain that which is desirable in the current system and improve upon undesirable system design.

- adopt improved technologies - rigourous implementation of newer technology such as more extensive use of high order language, design and code inspections, design standards, top down development and test, etc. should add to software quality while constraining its production costs.

- data collection - by collecting, categorizing, and maintaining data on all system failures and errors it will be possible to both quantify system reliability and pinpoint the source and cause of errors. This data will then allow the FAA to place emphasis on the techniques necessary to achieve higher quality software. This data collection should cover the entire software life cycle from concept through operation.

- further automation - investigate and implement methods to automate the most error prone, repetitive, and costly steps in software development. Emphasis should be placed on automation which will assist in identifying problems early in the software development cycle (such as unit testing) and then be expanded to cover later phases such as systems testing.

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APPENDIX F
PRIMARY RADAR TRACKING*

Primary Radar Data use in En Route Tracking

A brief examination has been made of the use of primary radar data in en route tracking. This was done using a sample of eight System Analysis Recording (SAR) tapes. The tapes were processed by the Track function of the Data Analysis and Recording Tool (DART), a software package at NAFEC. After processing by the Track function, an output tape was created with all aircraft track information organized by track ID. This tape was then processed by a small special purpose program to check for the use of primary radar data. This was done by examining the Correlation Preference Value (CPV) of each report for each aircraft. A CPV of 7, 8, 9 or 10 indicated the use of primary radar data. It is unknown how many primary radar reports were received, but were not processed or were decorrelated by a beacon report.

Attachment A lists the centers from which the SAR tapes came, the date and time or recording and number of tracks using primary radar reports out of the total number of tracks.

Attachment B lists the aircraft ID of the aircraft tracks using primary radar reports, the center from which the report was taken, date, track class, time duration of track, number of scans, number of scans of primary reports, and percent primary reports.

The percent of primary reports are based on the total number of subscans, and on the total number of reports received. With a subscan rate of six seconds and a radar rate of 12 seconds, the maximum percentage of primary reports to subscans could be 50%.

There seemed to be three general conditions when primary radar reports would be correlated. They are before establishment of a track, when an assigned beacon code is changed and when beacon reports are dropped for a period of time. In general, the dropped beacon reports did not appear to occur when an aircraft was turning or changing altitude. Attachment C lists the categories during which primary reports were correlated and the aircraft that fell into each category.

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* This appendix was prepared by Ronald Tornese, of The MITRE Corporation. The users considered this input as useful to their deliberations, but do not necessarily agree with or endorse the presented information.

ATTACHMENT A

Center	Date	Time	Tracks Using Primary Rpts	Total Tracks
Albuquerque	9/6/77	1543Z-1630Z	1	129
Atlanta	4/11/77 4/11/77 4/11/77	1859Z-1913Z 1913Z-1930Z 1930Z-1946Z	4	432
Boston	6/1/78	1739Z-1823Z	3	172
Denver	3/18/77	1821Z-1908Z	3	292
Denver	7/12/77	1606Z-1627Z	2	228
Denver	7/12/77	1826Z-1834Z	0	184
		214 min.	13 1.0%	1437

ATTACHMENT B

Altitude For Primary Radar (K ft)	ACID	Center	Date	Track Class	Track Duration	Total Subscans	Primary Reports	% Primary of Total Subscans	% Primary of all Reports Received
10	YYY1	ALB	9/6/77	Primary	41:36 min.	417	92	22.1	92.0
2	N18W	ATL	4/11/77	Beacon	4:12	43	1	2.3	100.0
28	N44FE	ATL	4/11/77	DB*	7:36	77	5	6.5	14.3
6	N4986N	ATL	4/11/77	DB*	16:24	165	1	0.6	1.8
20	N7728Y	ATL	4/11/77	DB*	31:42	318	4	1.3	2.9
10	AA407	BOS	6/1/78	DB*	19:18	194	1	0.5	1.0
22	AL375	BOS	6/1/78	DB*	13:48	139	36	25.9	61.0
10	N740R	BOS	6/1/78	DB*	41:42	417	4	1.0	2.6
20	MATER41	DEN	3/18/77	DB*	38:00	381	2	0.5	1.3
13	N1835M	DEN	3/18/77	DB*	43:48	439	19	4.3	90.5
39	UA187	DEN	3/18/77	DB*	23;36	237	1	0.4	0.8
10	N1091V	DEN	7/12/77	DB*	20:06	202	11	5.4	68.8
34	UA154	DEN	7/12/77	DB*	17:18	174	5	2.9	6.0

* Discrete Beacon

ATTACHMENT C

PRIMARY REPORT USAGE	TRACKS
Prior to Beacon Track Being Established (Track may be in Center to Center Handoff)	YYY1, N4986N, AA407 AL375, N1835M, UA187, N1091V, UA154
Aircraft changing Beacon Code	N44FE, N7728Y, N740R
Beacon reports missing	YYY1, N18W, MATER41

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NEW ENGINEERING & DEVELOPMENT INITIATIVES --
POLICY AND TECHNOLOGY CHOICES

Chapter II

APPENDICES

AIRPORT CAPACITY
Topic Group 2

APPENDIX B

The Influence of Present E&D Programs on Airport Capacity

Interim Report - Task 1

Economics & Science Planning, Inc.
Contract Number: DOT-FA77WA-4001

July 3, 1978

FAA E&D programs have been examined to determine how they relate to each other and to assess their contribution to meeting forecasted aviation growth patterns over the next twenty years. Aviation forecasts and E&D programs can be categorized in many ways. For the purpose of this report, it is useful to classify them into two groups, near term up to the year 1990, and reasonably predictable on the one hand, and long term up to the year 2000 and less predictable on the other hand.

The Limited Ability to Forecast the Capability of E&D Products

We can be more certain of ten year forecasts of the capability of E&D products than we can be of 20 year forecasts. For example, the first generation of wake vortex advisory equipment is predicted, in airport capacity studies, to have the capability of reducing vortex-limited separations 40% of the time. This system has a reasonable chance of meeting this objective within the next five years based on meteorological measurements at various airports. But there is less confidence that within the next two decades the more advanced wake vortex avoidance system (WVAS) will meet the predicted capability of reducing vortex-controlled separations 75% of time. There is little

experience with tracking of discrete vortices or with incorporation of such a tracking capability into a wake vortex avoidance system (WVAS). Therefore the predicted capability of WVAS is little more than an educated guess.

The M&S system is another example of this situation. Not only is there some doubt about the ability of basic M&S to deliver aircraft to the approach gate with an 11 second accuracy, there is not very convincing evidence that controllers now deliver aircraft with the presumed 18 second accuracy. Nevertheless, there is some probability that an M&S system will be implemented within the next decade that will be able to generate conflict-free vectors so as to deliver aircraft to an approach gate from the approach fix with an interarrival error of 11 seconds. One can only hope that eventually it will be possible to improve this delivery accuracy to 8 seconds. However, at this time there is no experience to support such an estimate.

The Limited Ability to Forecast Aviation Activity

The situation with respect to forecasts of aviation activity is similar. Presentations to the Subcommittee on Transportation, Aviation and Weather of the Committee on Science and Technology compared actual to forecast growth over the past 20 years - as shown in Figures 1, 2, and 3 - and concluded:

"The results of this comparison, as you can see, are rather distressing...The forecasts, regardless of when or by whom they were made, have one thing in common: They all appear to have been heavily influenced by recent history...No forecast appears to have been successful in predicting significant changes in direction of growth."

This difficulty in predicting forecasted aviation activity and the longer term capabilities of E&D products is exacerbated by the long times that have been required historically to proceed from conception to implementation for many significant E&D programs.

For example, NAS took more than a decade to implement after acceptance by FAA as an E&D program. MLS and DABS will take, if implemented, more than two decades to implement. Less significant E&D programs, especially those that involve only software, have taken and are planned to take much less time to implement, for example, conflict alert, MSAWS and probably ETABS and TIPS.

The uncertainty of forecasts and the long time period experienced for implementation of E&D products suggest that an E&D policy might be recommended that would have various products developed and evaluated and ready to be implemented, if necessary, to meet worst case forecasts.

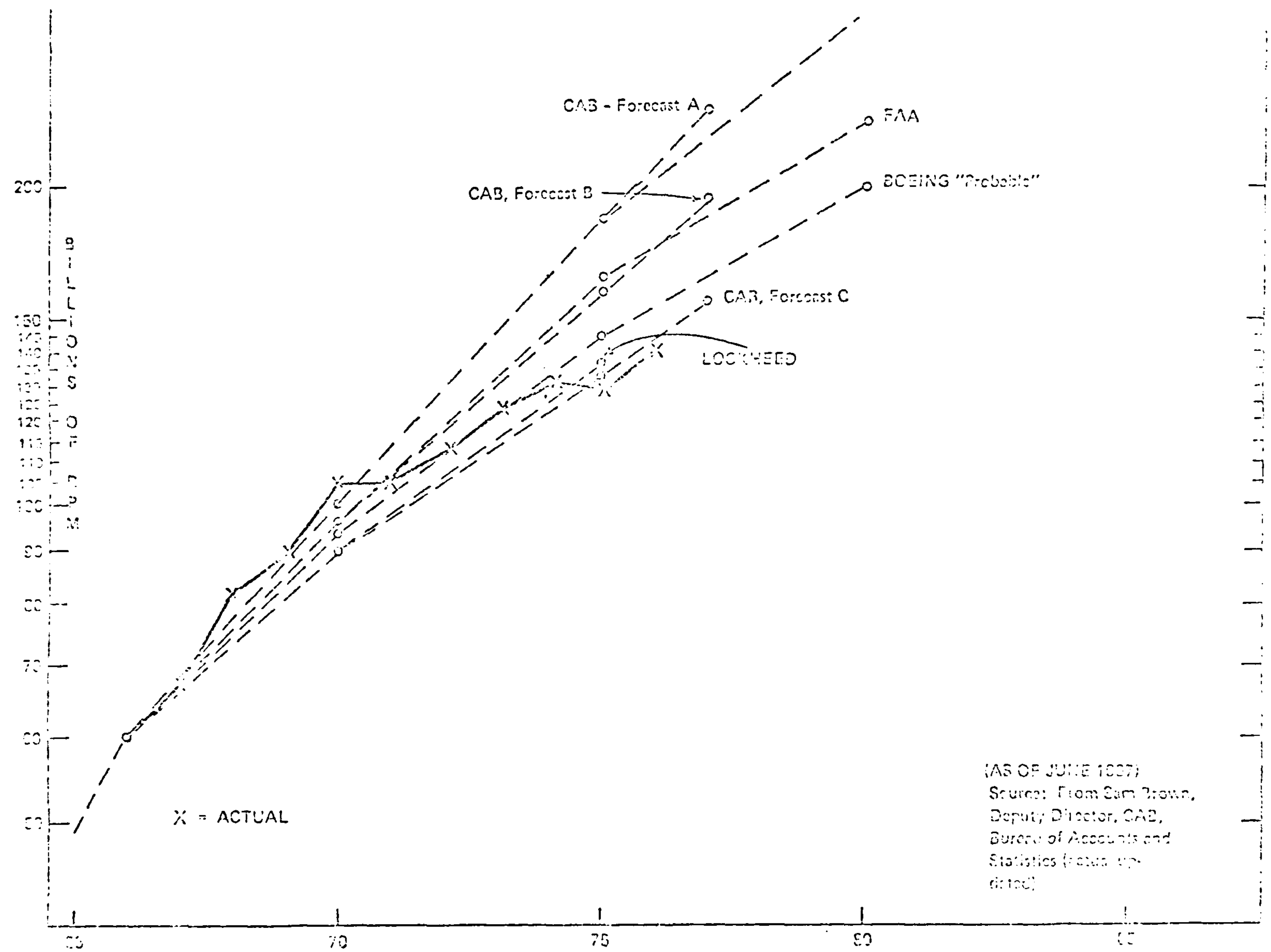

Figure 1 FORECASTS OF DOMESTIC TRUNK AIRLINE PASSENGER TRAFFIC —Unconstrained—

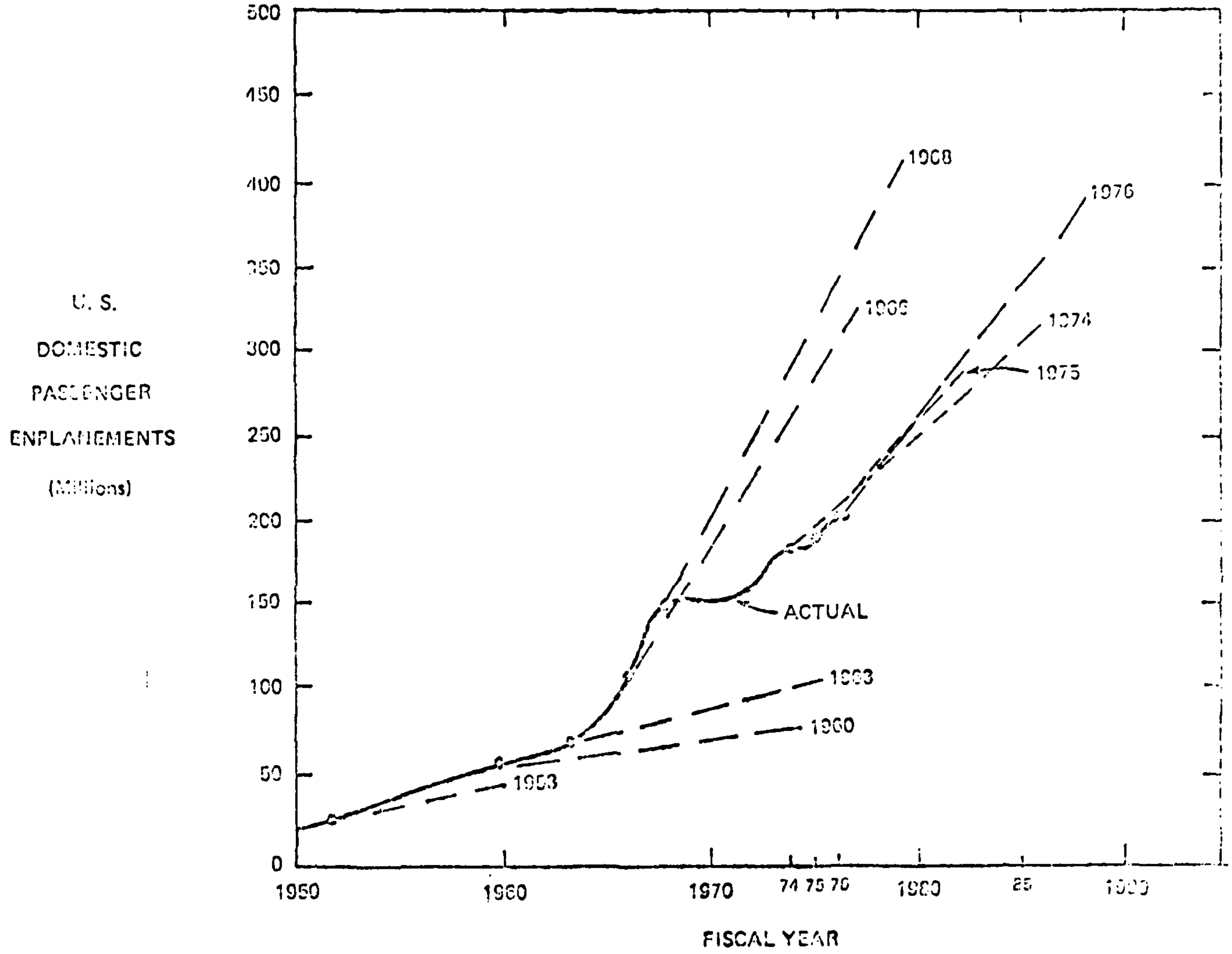

Figure 2 EFFECT OF RECENT HISTORY ON FORECASTS (FAA Forecasts)

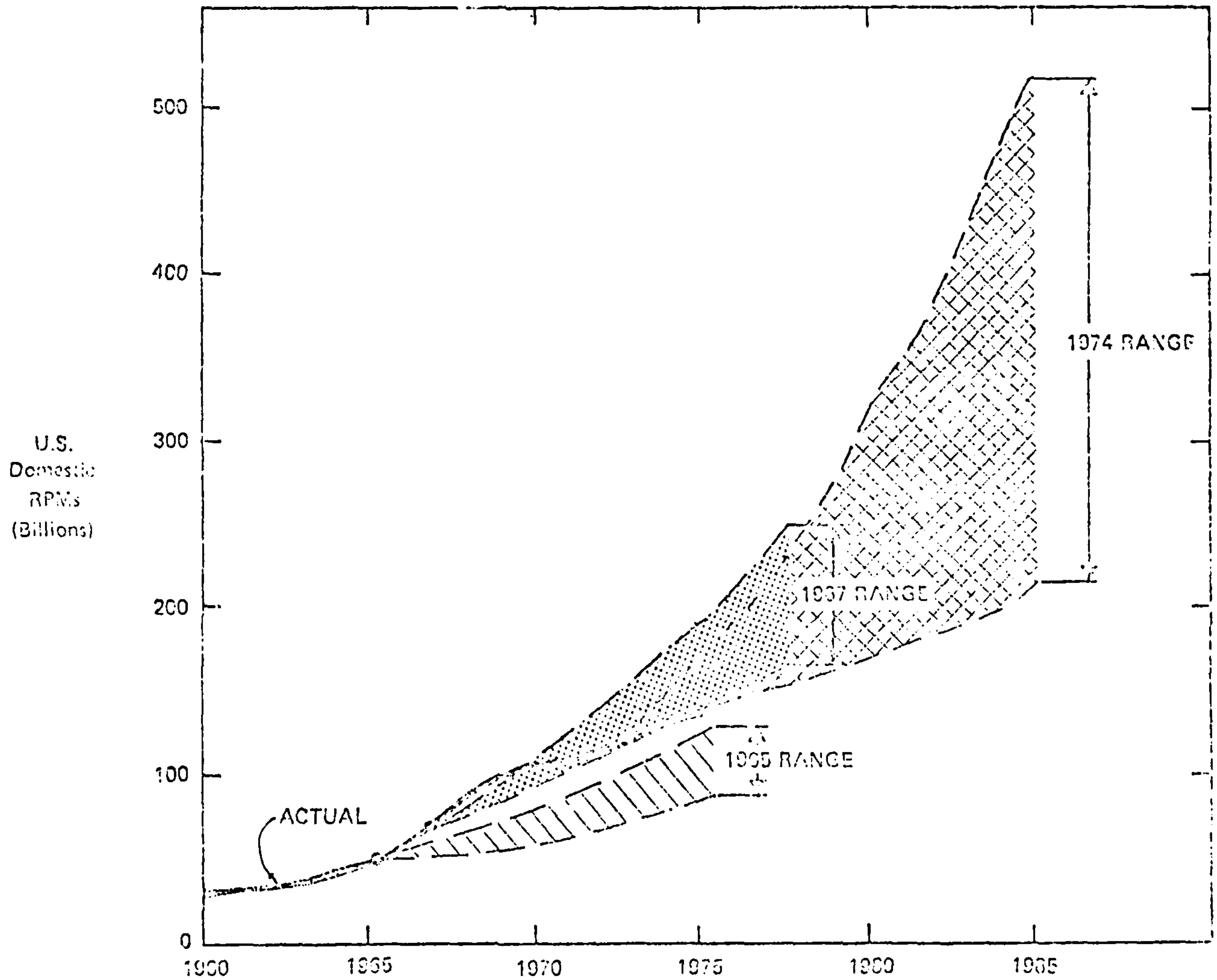

Figure 3 VARIATIONS IN CAB FORECASTS

Furthermore, since it seems that software programs are more expeditiously implemented than hardware, it would seem appropriate to implement E&D programs that have the capability for expansion and/or modification by software changes.

Not only is it difficult to accurately forecast aviation activity and the productivity of E&D developments, but even our understanding of the capacity and productivity of the current system is less than perfect. For example, predicted delays according to a recent report to Congress[1] do not agree with experimentally determined data compiled by the Office of Aviation Policy of FAA in comparable situations. This is shown in Table 1.

Table 1

Comparative Average Aircraft Delays for Two Airports (Minutes)

	Calculations from Report to Congress[1]		Experimental Data from AVP	
LGA	9	(339)	6.3	(335)
LAX	1.2	(493)	5.4	(466)

Note: The bracketed figures are the total average annual operations in thousands associated with the indicated delay.

[1] "Establishment of New Major Public Airports in the United States", DOT-FAA, August 1977.

Therefore, we compound an insecure understanding of how the current air traffic system's capacity and productivity depends on various parameters with even less certain activity forecasts and predictions on the capability of E&D products. Such a predicament recommends a high level of humility and the development of a variety of options.

Airport Capacity

There are summarized in Table 2 capacity and delay data for eight airports as follows: (1) Measured average aircraft delays; (2) Calculated delays in various time frames assuming forecasted growth and implementation of various E&D products; (3) Estimates of the extent to which the unconstrained 1987 forecast exceeds the saturation capacity; (4) Various predicted improvements in airport capacity measured with respect to a capacity diminished by an increasing proportion of heavy aircraft and due to Group 2 and Group 4 E&D products for VFR and IFR weather under various wake turbulence conditions; and (5) The net capacity increase with respect to present capacity due to Group 4 improvements.

One can conclude that the increase in unconstrained demand substantially exceeds the hoped for increase in VFR capacity arising from E&D products for every airport for which data is available. The projected increase in IFR capacity arising from E&D products is also less than the forecasted growth in unconstrained demand except for LAX and SFO. Moreover, the IFR increase in capacity arising from E&D products is

Table 2

A Comparison of "Unconstrainted" Demand, and Predicted Capacity Increase Due to E&D Products with Measured and Calculated Delays

	Airline Reported Average Delay/ Operation 1977 in minutes (1)	Calculated Average Delay/ Operation in Minutes (2) Present System 1975	1990	Configuration 2 - 5 Group 4 1990	Unconstrained Forecast 1987 Demand Exceeds Current Saturation Capacity (6 min. avg. delay) in percent (3)	Forecast Percent(4) Capacity Increase Group 2 VFR	IFR	Forecast Percent(4) Capacity Increase Group 4 VFR	IFR	Net Capacity Increase Group 4 VFR	IFR
Chicago O'Hare	5.9	8.65	17.09	6.33	34	4 (1)	5 (2)	22 (10)	36 (17)	14	31
NYC - LaGuardia	6.3	6.32	17.16	7.94	24	2 (2)	3 (2)	9 (6)	1 (8)	4	10
Denver - Stapleton	9.5	5.75	6.55	3.31	37	2 (2)	9 (4)	18 (7)	24 (17)	1	20
Los Angeles International	5.4	2.15	4.70	1.89	23	4 (3)	15 (3)	13 (11)	51 (27)	4	45
Atlanta Hartsfield	7.4	3.76	8.79	3.40	N.A.	5 (0)	9 (3)	16 (9)	17 (8)	5	-1
San Francisco International	6.1	5.82	62.54	18.52	11	5 (2)	11 (2)	9 (4)	34 (21)	6	32
Miami International	2.7	1.74	3.81	2.68	N.A.	5 (4)	0 (6)	12 (7)	5 (2)	8	1
NYC - Kennedy	6.8	6.48	63.58	13.00	N.A.	10 (1)	15 (2)	20 (12)	38 (22)	19	38

NOTES: (1) Data supplied by Eastern Airlines and United to AVP in FAA.

(2) "Estimation of UG3RD Delay Reduction", January 1977 DOT-FAA, FAA-AVP-77-7.

(3) "Unconstrained" demand excess is taken directly from Table IV, pp xxiii of "Terminal Area Forecast" 1978-1988, DOT-FAA, FAA-AVP-77-17.

(4) "Impact of FAA E&D Elements - Eight Airport Summary", Dr. A. L. Haines, September 1977, MTR-7350, Vol. VIII. The brackets indicate the "fallback" capacity increase limited by wake vortex.

Group 2 - Vortex Advisory System
Basic M&S - interarrival (1σ) error of 11 seconds
3-mile IFR separation for non-vortex impacted aircraft pairs with larger separations behind heavy aircraft up to 5 miles IFR and 4.5 miles VFR.

Group 4 - Wake Vortex Avoidance System
Advanced M&S & DABS - interarrival (1σ) error of 8 seconds
2-mile IFR separation for non-vortex impacted aircraft pairs with larger separations behind heavy upcraft up to 3.7 miles IFR and 3.4 miles VFR.

greater than the VFR increase in capacity. This is accounted for by the fact that present E&D products do more to equalize the present differences in IFR and VFR airport capacity than to improve VFR capacity. In the absence of wake vortex conditions, arrival spacing achieved today under VFR conditions may well be as small as can be achieved without reductions in runway occupancy time or violation of the principal of single aircraft occupancy on a runway at any given time so that E&D products cannot readily increase VFR capacity.

Looked at from a delay point of view, the airports that will have large delays (> 6 minute average delay per operation) are Chicago O'Hare, the New York hub airports, La Guardia and Kennedy, and San Francisco International. While the projected increases in capacity due to E&D products is less than the projected increase in demand for Denver and Atlanta, the delays experienced at these two airports will decrease due to additional runway construction.

The FAA delay study (FAA-AVP-77-7) used for part of Table 2 constrained demand at various airports in accordance with the projections of airport operators. The enormous average delay of 18.52 minutes/ operation projected for San Francisco International despite the capacity increase projected of 6% VFR and 32% IFR due to E&D products arises because the delay calculation was based on the 11% unconstrained demand increase projected in the Terminal Areas Forecast 1978-1988 (FAA-AVP-77-17) and because 80% of the traffic is VFR. The 6.33 minute delay projected

for Chicago O'Hare, utilizing E&D products that provide a capacity increase of 14% VFR and 31% IFR, is based on a constrained demand equal to only 75% of the unconstrained demand of the Terminal Area Forecast. So the delay calculation in Table 2 for O'Hare is based on a lower demand than the unconstrained demand forecast in Table 2. The delay would have been considerably greater at O'Hare if an unconstrained forecast had been used.

However it should be possible to provide almost a 50% increase in the capacity of Chicago O'Hare under IFR conditions (200 foot ceiling, 1/2 mile visibility) by using precision missed approach guidance, staggered arrivals on intersecting runways and improved surveillance on the present runway configuration as described in Appendix B1. Missed approach guidance can be provided by MLS, staggered arrivals on intersecting runways can be obtained readily to the precision needed by M&S and improved surveillance by DABS, perhaps operating at a somewhat higher data rate. These techniques isolate the northern tier of runways at O'Hare from the southern runways so that they can be operated as independent airports, and permit intersecting runways to be operated at a capacity almost that of independent parallels. By these techniques it is possible to continue to use a substantial portion of the O'Hare capacity, even triple arrivals and departures, as ceilings and visibility decrease. Thus improved capacity is obtained by fuller use of available runways under limited visibility conditions rather than by relying on decreased longitudinal separations. These techniques have been initially

analyzed in Appendix B1 for low or eastern winds. It seems that these techniques are applicable to other wind directions as well.

It also seems possible to add a short runway 2,500 feet to the west of the runway 14R as shown in Figure 4 and parallel to 14R which might be designated "15R." This runway could have a capacity of 40 operations per hour of low performance aircraft under all visibility conditions. This runway's threshold could be displaced downwind from that of 14R and the approach glide slope could be at approximately 4-1/2° as compared to the 3° glide slope for high performance aircraft using runway 14R. Thus a 1,000 foot altitude separation could be achieved between those aircraft on the approach course to 14R and those turning on to the approach course to "15R".

The 2,500 foot runway separation can be achieved safely as shown in Table 3[2] using a DABS interrogator and data link. DABS can provide an azimuthal accuracy of less than 1 milliradian and a 1 second data rate can be obtained either by mounting the DABS antenna on the ASDE radar or by back-to-back DABS antennas on a platform rotating at double the normal rate or by use of an electronically agile DABS antenna at this site. The selection of an improved surveillance system based on DABS should be done taking into account the probable need for an improved surface detection system at O'Hare, perhaps TAGS. The greater stability

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[2] "Reduction of Parallel Runway Requirements", MITRE Corporation, January 1973, DOT-FAA/OSEM.

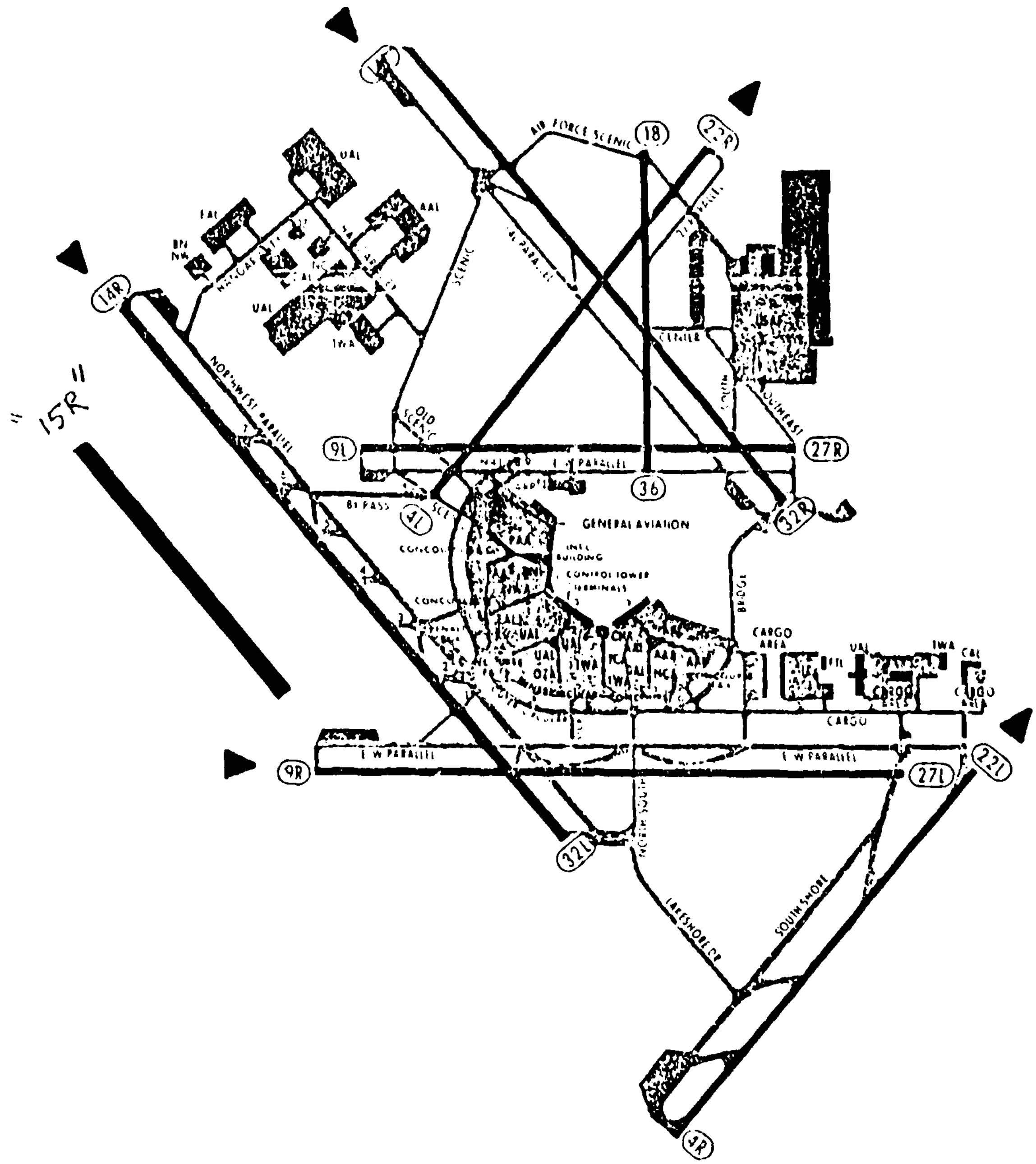

Figure 4

A General Aviation Runway at O'Hare

Table 3

Minimum Spacings Achievable

(Current Type Control System)

AZIMUTH* ACCURACY	DATA RATE			
	4 SEC.	2 SEC.	1 SEC.	
4 MR	4100	3800	3650	
3 MR	3900	3650	3500	
2 MR	3750	3500	3350	
1 MR	3600	3350	3200	
			2800	USE POSITION-VELOCITY CONTROL PROCEDURE
			2650	USE POSITION-VELOCITY-POSITION CONTROL PROCEDURE
			2500	REDUCE DELAYS TO 3 SECONDS (DUE TO DATA LINK)

* These azimuth accuracy requirements assume the radar antenna is aligned so that aircraft making their final approach are flying directly toward the antenna. The 1 MR requirement corresponds to a requirement of 40 foot accuracy when aircraft are between 5 and 6 nmi from the runway. Similarly, 2 MR corresponds to an 80 foot cross course accuracy requirement, 3 MR to a 120 foot accuracy requirement and 4 MR to a 160 foot accuracy requirement.

of MLS guidance as compared to ILS will also increase the feasibility of the 2,500 foot runway separation.

Operations on "15R" have to be coordinated with operations on 9R in the same manner as operations on 14R have to be coordinated with operations on 9R as explained in Appendix B1. Furthermore in order to ease aircraft surface congestion, it should be possible to park GA and commuter aircraft at a terminal between 14R and "15R" and to connect this terminal and the main O'Hare terminal by means of a tunnel under 14R for passengers.

This new manner of operation of O'Hare and the additional runway for low performance aircraft should together be able to provide almost a 100% increase in the IFR (200 feet, 1/2 mile) capacity of this key hub airport. This capacity increase can be obtained without resorting to 2-mile IFR separation for non-vortex impacted aircraft pairs or an advanced M&S system or an advanced wake vortex avoidance system. Thus the unconstrained "1990" demand at O'Hare can be almost satisfied with the addition of a runway for low performance aircraft and the use of MLS for missed-approach guidance, the use of a crude M&S (30 seconds) to control staggered arrivals and a DABS system with a scan rate of 1 per second. This situation is summarized in Table 4.

Table 4

O'Hare Capacity Improvements
(operations per hour)

	Current	Adding a Runway for Low-Performance Aircraft	Also Utilizing Precision Missed Approach Guidance and Staggering
IFR-(200 ft., 1/2 miles)	111-114	151-154	191-194
VFR-(3,500 ft., 5 miles)	172-180	212-220	212-220

The impact of Group 2 and Group 4 E&D programs is likely to increase the capacity indicated in Table 4 but not by the amount indicated in Table 2. More of the O'Hare runways are utilized to obtain the capacities indicated in Table 4 then are used to obtain the capacities shown in Table 2 and they are used in a different manner. Therefore it is necessary to apply the formal computational methodology used to derive the results presented in Table 2 to determine the increase in capacity that would obtain when Groups 2 and 4 E&D projects are superimposed on the additional runways and runway utilization assumed in Table 4. Such an effort is beyond the scope of this report.

The New York hub airports also have runways that could be used in such a manner as to increase capacity if FAA implemented precision variable approach and missed-approach guidance (presumably MLS) as well as improved surveillance (permitting staggered or independent arrivals). This would enable the restructuring of New York hub airspace so that JFK and LGA could operate independently of each other and it would also

permit a much more extensive use of the substantial number of runways already available on JFK. As in the case of O'Hare, implementation of these E&D products used in the manner described in Appendix B1, would increase JFK capacity by 40-80% under both IFR and VFR conditions without the need to resort to the decreased longitudinal spacing associated with the Group 2 and Group 4 E&D products. The utility of these E&D products becomes less important for JFK once independent arrivals and departures are achieved on the JFK runways and with some reduction of mean runway occupancy time. Under these circumstances the Group 2 and 4 E&D products add only 6-11% capacity improvement in addition to the 40-80% improvement achieved by the techniques outlined above and explained in greater detail in Appendix B1.

Utilizing the techniques outlined in Appendix B1 would seem sufficient to satisfy the "1990" unconstrained demand for JFK indicated in Table 2. Furthermore, such techniques would permit LGA to operate in its high capacity mode (arrivals on 22, departures on 13) a greater percentage of the time - since it would become independent of JFK operations. It is beyond the scope of this report to calculate the increase in LGA capacity due to its independence from JFK in addition to the increase in capacity provided by the Groups 2 and 4 E&D products. Such independence would have to add the 15-20% increase in capacity necessary to meet the unconstrained forecast of "1990".

Thus taking into account the techniques described in Appendix B1 for making better use of the available concrete at O'Hare and the New York hub airports, and the planned construction at Denver and Atlanta, San Francisco International becomes the one airport that evidently cannot handle "1990" demand.

APPENDIX B1

The Influence of Precision Missed-Approach Guidance and Staggered Arrivals on JFK and ORD Capacity[1]

The use of MLS to provide precision missed-approach and departure guidance -- in addition to its other functions -- and the potential use of M&S to provide and monitor an appropriate stagger between arrival streams on parallel or intersecting runways -- in addition to its other capabilities -- may provide significant capacity increases in the New York and Chicago hub airports and perhaps elsewhere. Preliminary calculations predict IFR capacity increases of 50% at JFK and 25% at ORD by being able to make more extensive use of existing runways and without having to decrease longitudinal separations. This is a preliminary note to be used as one input to a task force on capacity.

For example, simultaneous parallel approaches to runways 31 L/R at JFK are not now permitted because current missed-approach and departure procedures particularly from 31 R would cause interference with LGA airspace. A precision guidance capability -- most accurately provided by MLS[2] -- might provide departure and missed-approach courses that

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1/ This note was prepared with the help of Andrew Haines and Michael Harris of the Metrek Division of MITRE Corporation.

2/ RNAV might be used, but it provides less accuracy and might not be acceptable in many situations.

would turn both courses to the left of runway centerlines, thereby avoiding LGA airspace, while still providing the necessary divergence between departure and missed-approach courses. The missed-approach divergence is now specified to be 45°. It is being reviewed by the Air Traffic Service to see if it can be reduced to 15°. This is the current divergence criteria for departures from parallel runways. Should 31 L/R approaches be staggered, the missed-approach guidance requirement becomes less demanding.

The involvement with LGA airspace is still less if a dual stream of arrivals can be accomodated on 22 L/R at JFK[3]. The JFK capacities that might be achieved are shown in Figure 1 for the two runway configurations in comparison with task force estimates that pertain to current operating practice that uses the parallel runways as dual lanes. It can be seen from the 5th column in the figure that a 2-nautical mile stagger does cause a capacity penalty as compared to independent arrival and departure streams. The stagger, however, does ease missed-approach problems for the 31 set of runways and provide separation assurance for the 22 set of runways which are 3,000 feet apart. The 4th and 6th column indicates that runway occupancy time limits JFK capacity more so than at other

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3/ A procedure for accomplishing this has been proposed by Air Traffic, however this rule would have to be modified to be applicable to arrivals on 4 L/R or in other situations because of the need for missed approach guidance.

Figure 1 - IFR Hourly Capacity at JFK under Various Procedures

	31's	22's	EITHER CONFIGURATION			
	TASK FORCE DUAL LANE	TASK FORCE DUAL LANE	2NMI STAGGER	2NMI STAGGER PLUS REDUCTION IN MEAN RUNWAY OCCUPANCY TIME TO 60 SECONDS*	INDEPENDENT AR/DEP	INDEPENDENT AR/DEP PLUS REDUCTION IN MEAN RUNWAY OCCUPANCY TIME TO 60 SECONDS*
Today	53	57	74	77	87	92
Group 2	63	64	79	83	92	98
Group 4	75	77	85	90	97	104

* All cases, in all E&D time frames, are limited by runway occupancy times (means for task force were 63 seconds and 70 seconds for large and heavy aircraft, respectively). Improved exits should permit mean runway occupancy times of 60 seconds.

airports and greater capacity could be obtained by the construction and use of high speed exits.

The simultaneous use of staggered approaches and precision missed-approach and departure guidance might also allow the use of the 4 L/R and 13 L/R runways at JFK without intrusion into LGA airspace and with separation assurance even though the 4 L/R runways are 3,000 feet apart.

For runways 3,000 feet apart, a 2 NMI diagonal stagger implies a longitudinal spacing of approximately 6.5 NMI on each approach course. This estimate of longitudinal spacing consists of three elements:

(1) The spacing to maintain a 2 NMI diagonal stagger at 3,000 feet runway separation 2 X 1.94 = 3.88 NMI

(2) The two (one for each stream of traffic) M&S buffers of 1.65 σ (.05 violation) with σ = 18 seconds added statistically $\sqrt{2}$ x 1.65 x 18 = 42 seconds equivalent at 130 knots to = 1.52 NMI.

(3) Buffer of 25.7 seconds for final approach speed differentials of 120-140 knots over an assumed 6 mile approach path corresponding to 130 knots = .93 NMI

This longitudinal spacing is larger than that required to release a departure between every arrival which is approximately 5 nautical miles for the large runway occupancy times encountered at JFK. Since the M&S buffer of 18 seconds represents an interarrival error, there is a question as to whether two such buffers are needed. But it is not a very important question, since the capacity obtained with a dual stream of staggered approaches and departures, column 3 of Figure 1, is 50% greater than the capacity utilizing the runways as dual lanes, columns 1 and 2, even though the longitudinal separations are approximately 50% greater.

An MLS approach system implies a smaller approach path from the approach gate to runway threshold, decreasing the required longitudinal spacing and increasing the capacity. A more precise M&S system than σ = 18 seconds would also decrease the required longitudinal spacing and increase the capacity. This accounts in part for the increased capacity of the group 2 and group 4 configurations for staggered approaches.

The implications of Figure 1 are rather staggering, by making better use of the concrete at JFK and the airspace between JFK and LGA by means of precision departure and missed-approach guidance probably using MLS -- and staggered approaches to parallel runways -- that could be facilitated by an M&S system -- a 50% capacity improvement can be obtained at longitudinal spacings consistent with today's vortex separation requirements. This is true for a balanced arrival/departure demand. Additional work is necessary to confirm these results and to treat unbalanced demand.

Figures 2a and b sketch present approach and departure paths in the LGA-JFK airspace. It can be seen from Figure 2a that minor routing changes could accommodate the staggered approaches on 22L/R. However from Figure 2b, it can be seen that it may be necessary to bring arrivals to LGA 31 from the north rather than south to accommodate staggered approaches and departures on JFK 31L/R. The requirements of various routing schemes for precision terminal guidance have to be investigated.

A somewhat similar possibility exists at ORD. The high capacity triple arrival configuration shown in Figure 3 is operable only at ceiling/visibility conditions of 3,500/5 or better. This is in part due to missed-approach difficulties under more limited ceiling/visibility conditions. For example, configuration 13 of Chicago's O'Hare Delay Task Force Study calls for triple arrivals on 14 L, 14 R and 9 R, with departures on 4 L and 4 R. Capacity is maximized to the extent these runways can be operated independently. Obviously 14 L and 4 L under all visibility conditions must be operated as a crossing runway. Under good visibility and runway conditions 14 R and 9 R are essentially independent arrival runways assuming arrivals on 14 R can stop short of the 9 R (Tl) intersection. 4 R is a departure runway where releases are dependent on 9 R arrivals but independent of 14 R arrivals under most visibility conditions and independent of 14 L arrivals under good visibility conditions. The total capacity of this configuration has been estimated to be 172-180 hourly operations. However it is unbalanced accommodating

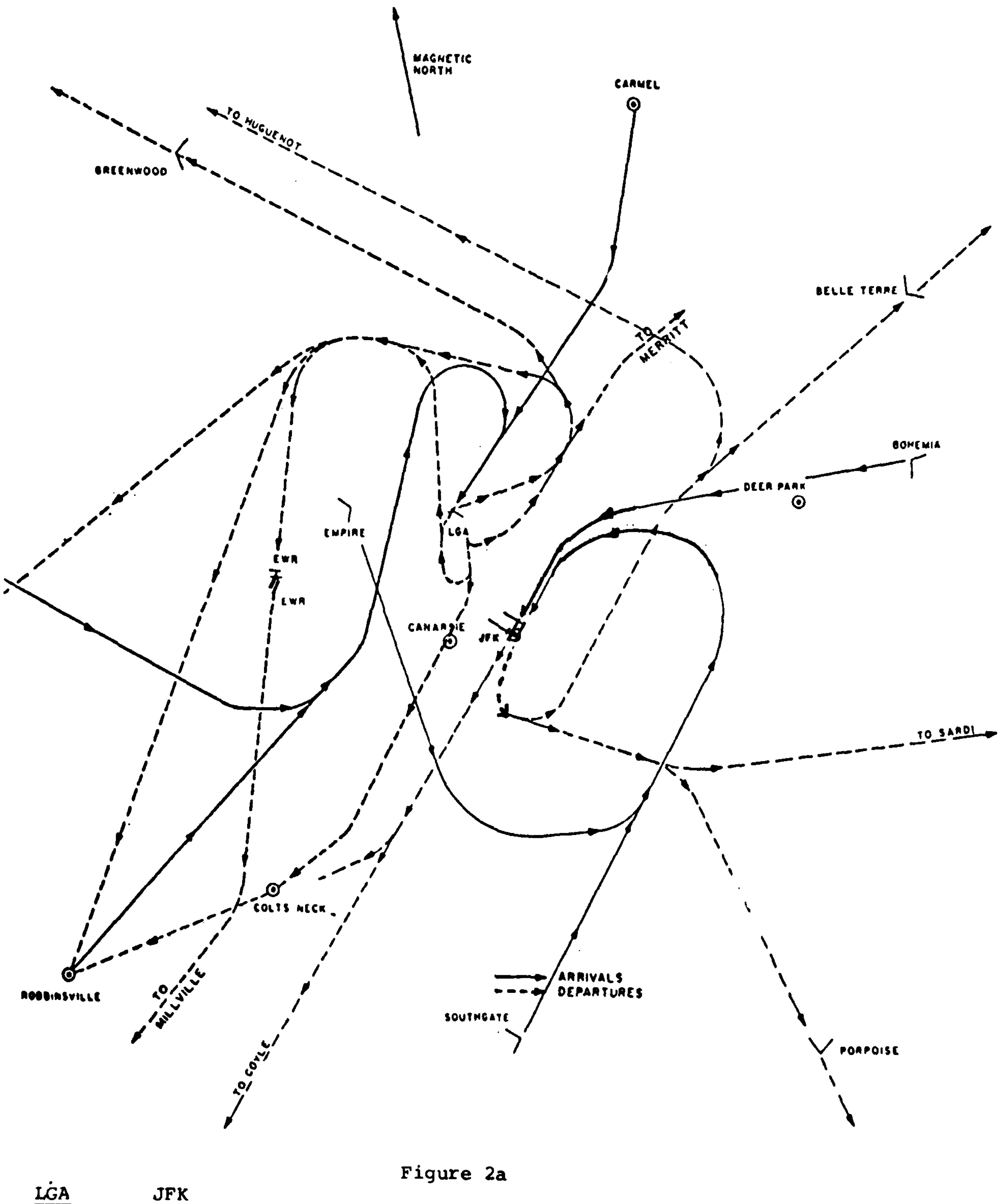


Figure 2a

LGA	JFK
A22	A22 L/R
D13	D22 L/R

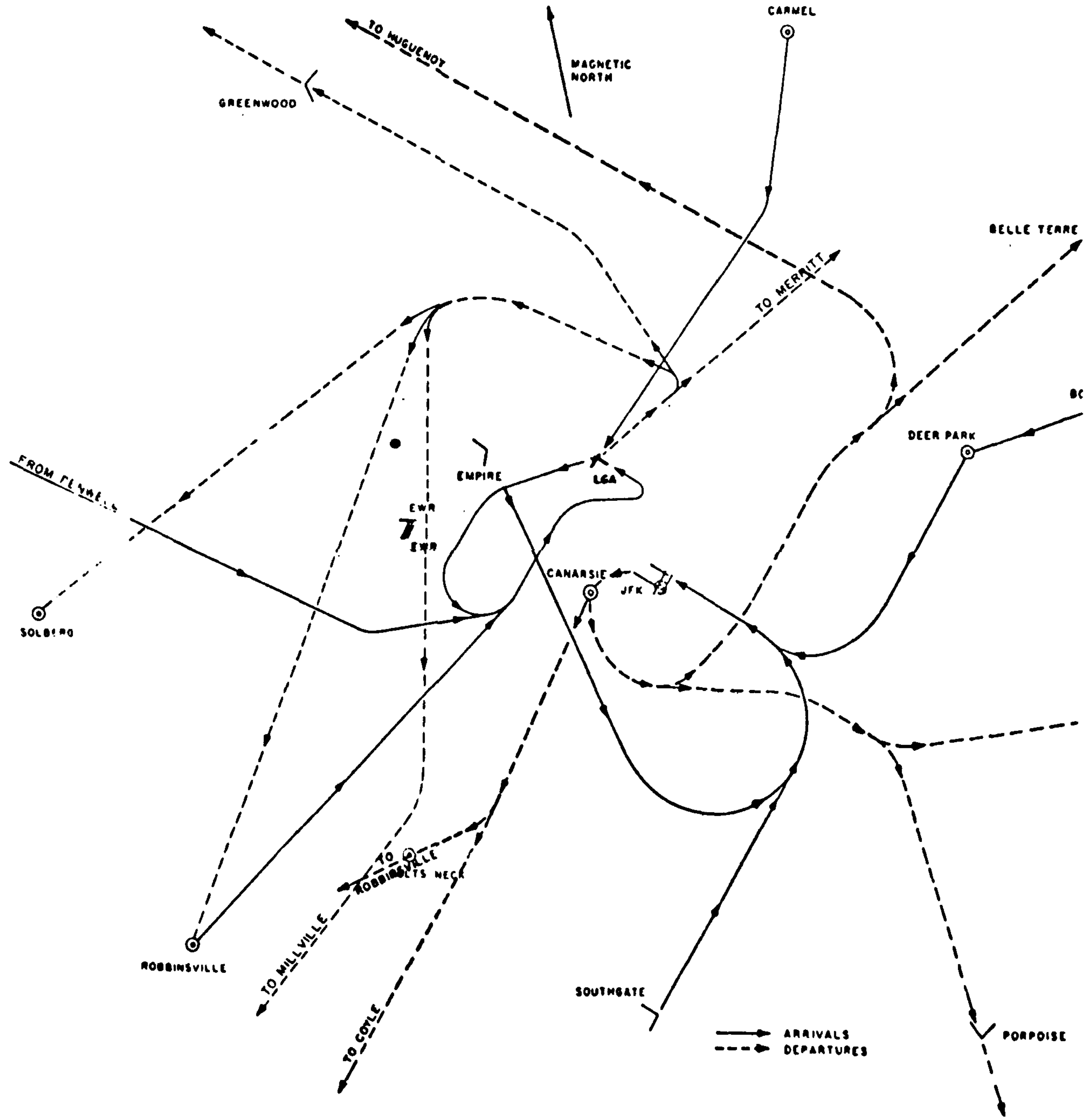
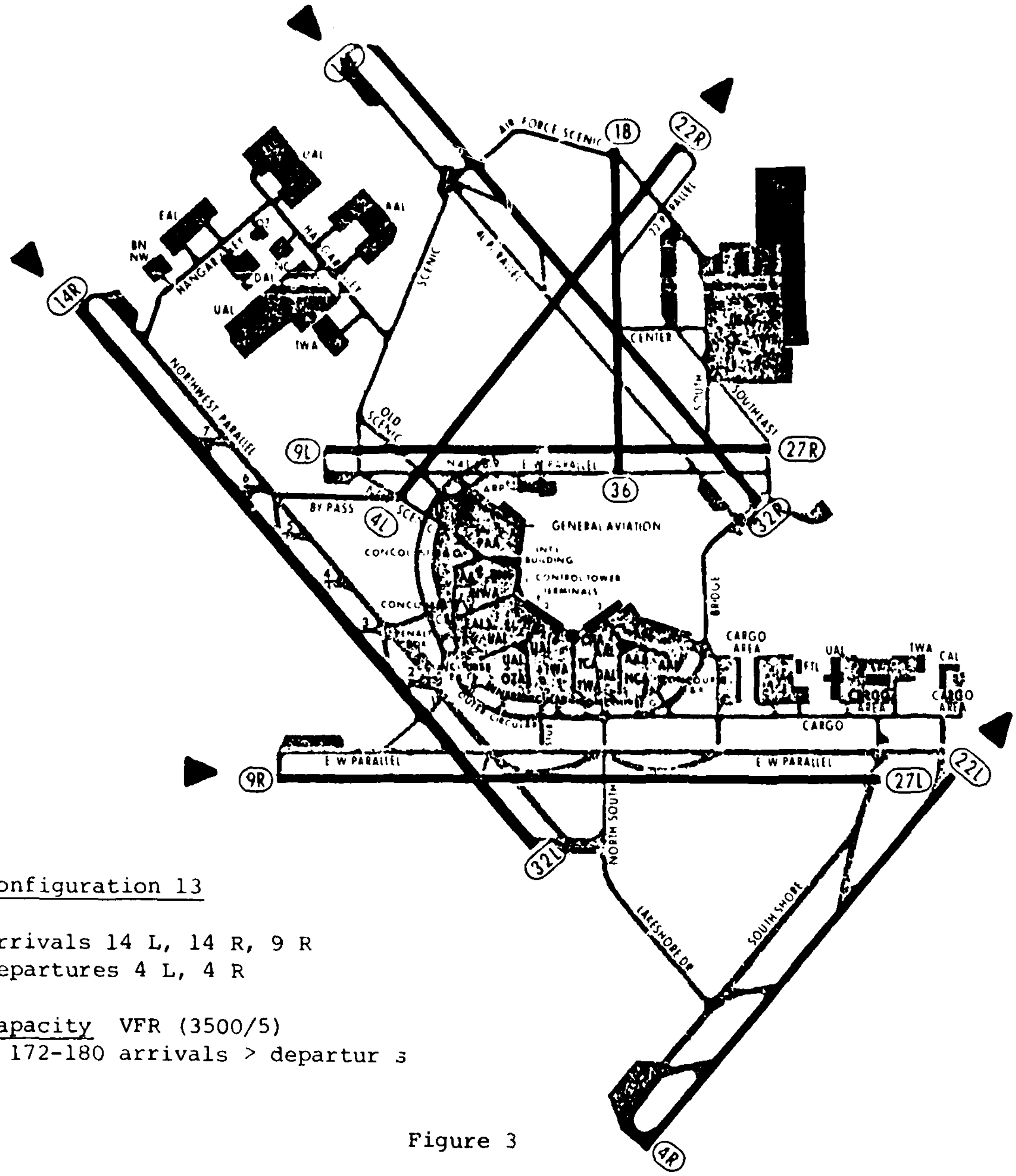


Figure 2b

LGA	JFK
A31	A31 L/R
D4	D31 L/R



Configuration 13

Arrivals 14 L, 14 R, 9 R
Departures 4 L, 4 R

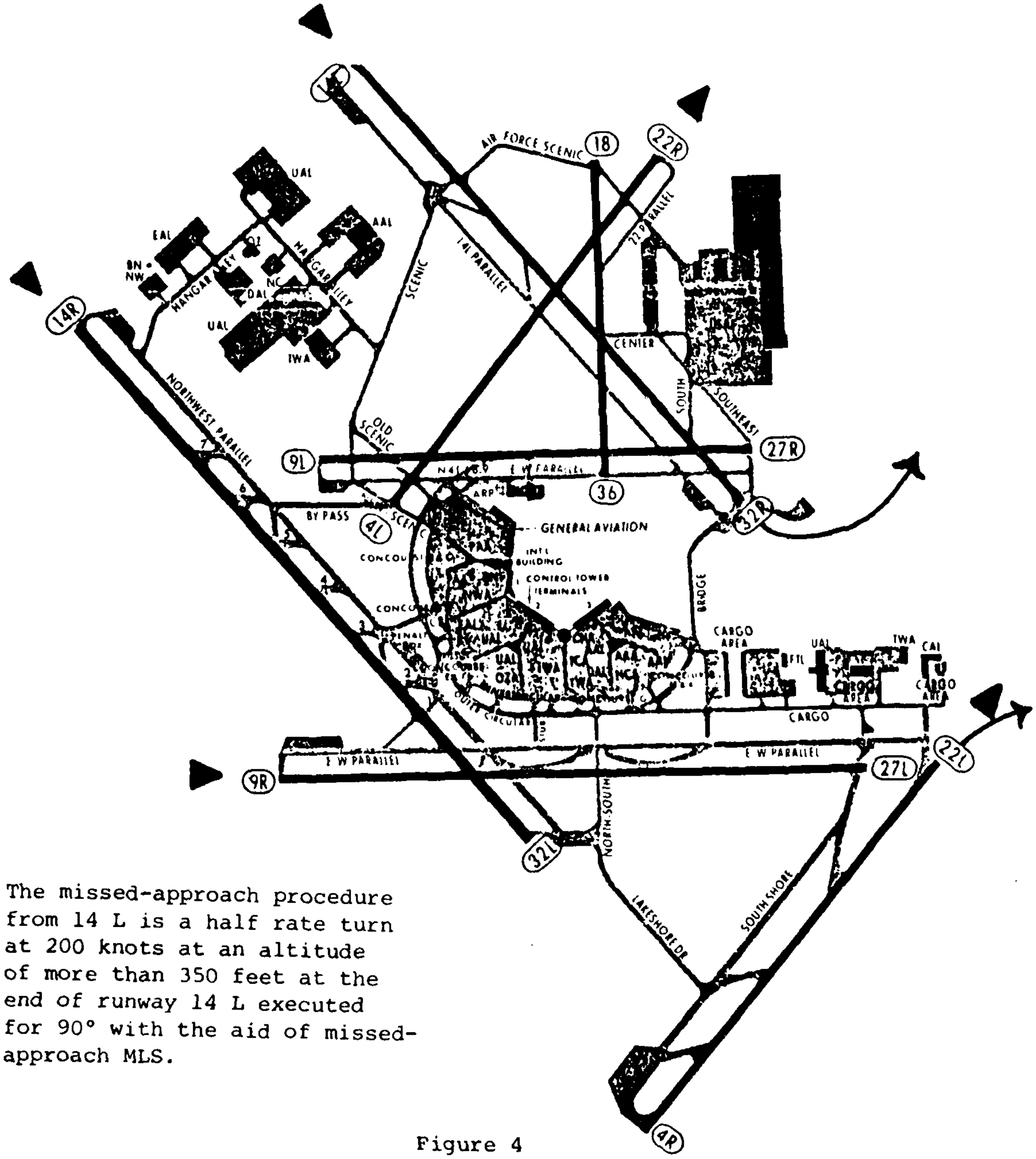
Capacity VFR (3500/5)
172-180 arrivals > departur s

Figure 3

more arrivals than departures. This capacity is 50% greater than the IFR capacity (ceiling/visibility 200 feet/1/2 mile) of any O'Hare configuration.

It seems possible to lower the minimums for operation of configuration 13 from the present 3,500/5 by the use of MLS missed-approach and departure guidance (in addition to its other functions) and by the use of M&S to achieve staggered arrivals to runways 14 R and 9 R. The application of these technologies is to minimize runway interactions under low visibility conditions. For example, in Figure 4 arrivals on 14 L and departures on 4 L can operate as an arrival/departure complex capable of 56 operations per hour under low minimum conditions. This northern runway complex might be "decoupled" from the remaining southern runway complex at O'Hare if the missed-approach procedure from 14 L could be a half rate standard turn for 90° from the end of the runway to a heading that diverges from departures on runway 4 R and that is precision guided by missed-approach MLS.

Runway 14 L is 10,000 feet long. An aircraft committed to a missed-approach should be in a climb out configuration by the time it is 3,000 feet down the runway. At the end of the runway, an altitude of at least 350 feet should be obtained permitting a 15° bank half rate turn. The 14 L missed-approach course would then be parallel to the 4 R runway and could diverge from 4 R departures by either having these departures precision guided on a departure heading somewhat greater than 40 or by



The missed-approach procedure from 14 L is a half rate turn at 200 knots at an altitude of more than 350 feet at the end of runway 14 L executed for 90° with the aid of missed-approach MLS.

Figure 4

Missed-Approach & Departure Procedures on 14 L and 4 R

continuing the half rate turn from 14 L for somewhat more than 90°. These guided missed-approach and departure courses are shown in Figure 4.

The closest approach between the 4 L departure path and the 14 L missed-approach is 2/3 nautical miles. However both aircraft would be under precision guidance by MLS and on diverging paths. Moreover, assuming that the 4 R departures are independent of the 14 L arrivals and that the missed-approach rate is 0.01 under IFR conditions (200 feet/1/2 mile) with MLS approach guidance, the probability of two aircraft being within 2/3 nautical miles is less than 1 in 1,000 as shown in Figure 5. Since the IFR condition, 200 feet/1/2 mile, occurs only 1% of the time, the probability of two aircraft being within 2/3 nautical miles is 1 in 100,000 landings.

Alternatively, wind conditions permitting, departures could take place on 22 L rather than 4 L, so that there would be only missed-approach interactions between 14 L and 9 R. The probability of a missed-approach from 9 R being this close to a missed-approach from 14 L is less than 1 chance in 100,000. This probability becomes 1 chance in 10,000,000 when one takes into account the probability of this IFR weather occurring. The missed-approach course from 9 R could also be precision guided to the right of the runway centerline so that the missed-approach procedure from 14 L would only require a 45° half rate

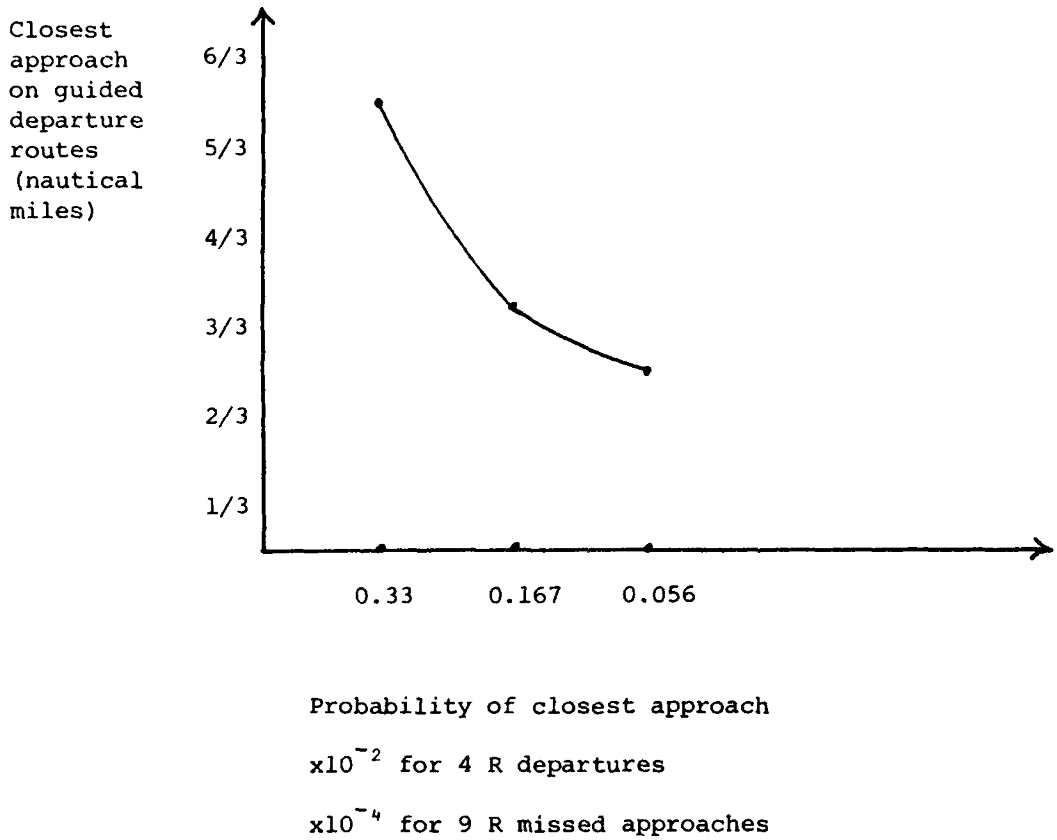
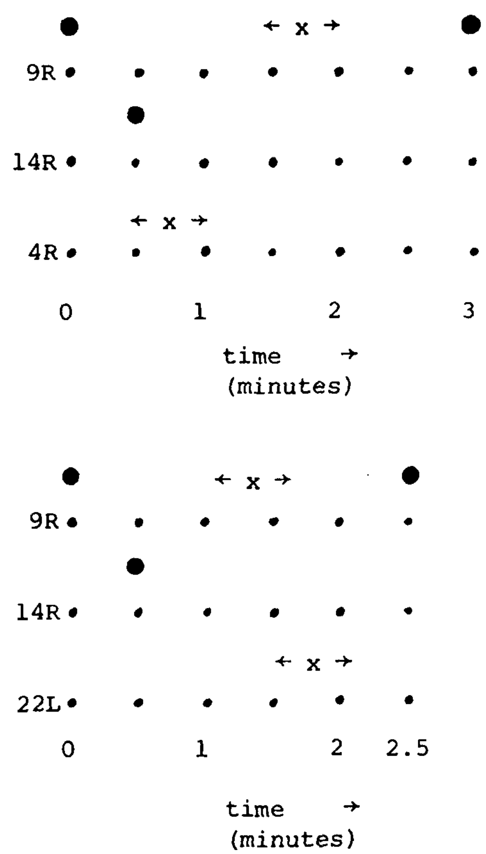


Figure 5 - Probability of Closest Approach Using MLS Missed-Approach Guidance at O'Hare.

turn and the two missed-approach courses would still diverge. If these procedures cannot survive detailed analysis, the departures on 4 R and perhaps even the arrivals on 9 R must be coordinated with arrivals on 14 L which would probably over-constrain the entire runway complex and reduce capacity substantially.

Assuming the missed-approach procedures on 14 L and the departure and missed-approach procedures on 4 R and 9 R can effectively isolate the northern from the southern runways, the timing diagrams shown in Figure 6 apply to various utilizations of the O'Hare runways on the southern part of the airport. The arrival on 14 R is delayed 30 seconds, after the arrival on 9 R by an M&S system. The arrival on 9 R will thereby have cleared the intersection before the arrival on 14 R touches down. The departure on 4 R can be released as soon as it is certain that the 9 R arrival will not execute a missed-approach. The 4 R departure is relatively independent of the 14 R arrival since a missed-approach on 14 R will pass over a 4 R departure before it leaves the ground. Furthermore, the 14 R missed-approach MLS guidance could call for a slight turn to the right so as to avoid the 4 R runway altogether.

The timing diagrams indicate that it should be possible to release a departure on 9 R if the arrival stream is opened up to three minutes on the average as compared to 2.1 minutes average for the 14 L/4.L runway complex. There would then be a balanced capacity of 68 arrivals and 68 departures. The 9 R departure can only be released after the 4 R



Key: x - departure
● - arrival

Figure 6 - Timing Diagrams of O'Hare Runways

departure has cleared the runway or approximately 60 seconds after the 4 R departure. The 9 R departure must be released before the next 9 R arrival is less than two nautical miles from the runway threshold or approximately 60 seconds before the 9 R arrival. This timing sequence therefore provides 30 second "windows" during which it is possible to release the departures on 4 R and 9 R without interference from or to the 9 R arrivals. These buffers seem to be sufficient to compensate for interarrival errors between the 9 R and 14 R arrivals and the length of time necessary to insure that 9 R arrivals are committed to a landing.

Wake turbulence interaction at the intersection of the 9 R and 4 R departure routes can be minimized by having light aircraft utilize 4 R and heavy and large aircraft use 9 R for departures. Then the spacing between light and other aircraft would be two minutes. Additionally the light aircraft should be able to climb over the region of wake turbulence interaction because of their greater climb rates. When wake turbulence rules are in effect, a three minute interval is required at an intersection on a runway. There is some question as to whether this rule or a 5-mile separation rule or just what rule would apply in this situation. Wake turbulence effects persist in light winds, but under these conditions, departures could take place on 22 L rather than 4 R thereby avoiding the wake turbulence interaction between 9 R and 4 R altogether.

The complete cycle of arrivals and departures on the three runways takes 3 minutes, yielding 40 arrivals and 40 departures which when added

to the 56 operations on the 14 L/4 L complex yields a balanced arrival/ departure total of 136 as compared to 114 operations under apparently similar ceiling/visibility conditions.

If an excess of arrivals has to be handled, the departure on 9 R could be omitted and the average interarrival time on the 14 R/9 R/4 R complex of runways could be reduced to that of the 14 L/4 L runway complex, namely 2.1 minutes. In this case there would be 56 arrivals on 14 R/9 R complex plus 28 arrivals on 14 L leading to 84 arrivals and 28 departures each on 4 L and 4 R leading to 56 departures, or a total of 140 operations. In the light wind case the 22 L departure is released after the preceeding 14 R arrival lands as indicated in the timing diagram, Figure 6. However the timing is such as to permit a 2.5 minute rather than 3 minute cycle as shown, leading to 152 hourly operations. These approximate results are shown in Figure 7.

Here again, as in the case of JFK, capacity is obtained by making better use of existing concrete by minimizing runway interferences through the possible use of MLS and M&S rather than by decreasing longitudinal separation.

Other runway configurations should be examined and the implications of changes in the aircraft mix and future E&D implementations should be calculated. Furthermore, a more detailed calculation of capacity should

Figure 7 - O'Hare Capacities

Arrival	27 R, 27 L	14 L, 14 R	14 L, 14 R, 9 R	14 L, 14 R, 9 R	14 L, 14 R, 9 R
Departure	32 R, 32 L	9 R, 9 L	4 L, 4 R[1]	4 L, 4 R, 9 R[2]	22 L, 4 L, 9 R
Configuration type	1 Crossing 1 Arrival 1 Departure (Task Force)	1 Crossing 1 Arrival 1 Departure (Task Force)	Crossing (14 L/4 L) Dependent arrival (9 R) with arrival (14 R) with departure (4 R)	Crossing (14 L/4 L) Dependent arrival (9 R) with arrival (14 R) with departure (4 R and 9 R)	Crossing (14 L/4 L) Dependent arrival (9 R) with arrival (14 R) with departure (22 L and 9 R)
Today	114	114	130-140	136	152
Group 2	125	115	---	---	---
- mix	114	114	---	---	---
Group 4	164	129	---	---	---
- mix	108	108	---	---	---

1/ Unbalanced arrivals/departures

2/ Balanced arrivals/departures

be made using actual longitudinal spacings and aircraft speeds on final rather than average spacings as in the timing diagram of Figure 6. Such a calculation would determine whether the average interarrival period of 2.1 or 2.5 or 3 minutes would be sufficient to assure a 14 R arrival 30 seconds after a 9 R arrival for all speed and weight class mixes.

APPENDIX C

IMPACT OF AIRCRAFT NOISE CONSIDERATIONS ON THE NATIONAL AIR TRANSPORTATION SYSTEM

Presented Before The Airport Capacity Topic Group

Of The FAA Engineering And Development Initiatives Program

by

J. M. Schwind

Deputy Manager for Engineering

Air Line Pilots Association

I. DISCUSSION

A. Background

In 1952, General Jimmy Doolittle, as head of the President's Airport Commission, wrote:

> "The immediate problem is to find a way to protect present airports and the people residing near them by applying some means of control of ground use in approach zones. Local authorities should prevent further use of land for public and residential buildings near the ends of existing runways. If this is not done, new contingents of homeowners will be added to the ranks of those who are now protesting against noise and hazard. In time, public pressure may threaten the continued existence of the airport and large investments of public and private funds will be jeopardized."

At some point in time, and soon, we must all come to realize the price paid for a quarter-century's inactivity and inattention to the problem cited in the Doolittle Report. The nation's air transportation system is presently backed into a corner, airports are ceasing to exist, and large amounts of public and private funding are in jeopardy. Today, twenty-six years later, the quote above is not only relevant but also an understatement.

As the situation stands now, the aviation community is faced with a continuing series of attacks from communities surrounding airports. This pressure has brought about situations such as:

- Los Agneles' purchase of $144 million worth of land or easements surrounding Los Angeles International Airport and payment of $26 million in court settlements related to noise.
- The projected collective expenditure, by carriers, of $1 billion to retrofit 1600 air carrier aircraft with "quiet" engines.
- The incalculable loss of community accessibility to passenger and freight traffic threatened by the airport curfews.

On the whole, the current status of the aircraft noise issue is discouraging. Public pressure, voiced through the ballot box and through litigation, is proving effective in creating action throughout the country that reduces system capacity and, in some cases, reduces the level of safety of air transportation. Logically, then, it is not possible to consider expansion of the air transportation system while the world closes in around it.

In a time when we are faced with reliever airport closures, runway use restrictions, and curfews, the metering effect of passenger terminals or access roads should be a minor concern. Technological improvements that facilitate greater amounts of air traffic are pointless if there are not runways to launch and recover aircraft from. The primary capacity issue for the entire aviation community should be the problem of Noise Constraints.

As a community, we must take action to halt erosion of present system capacity. Concerted efforts to alleviate noise in airport communities can both preserve present airport resources and lay the foundation for expanding these resources to meet the needs of the expanding population. Delay in initiating a rationalization of noise abatement efforts will assure that presently unused land is occupied by tenants incompatible with aircraft operations. However, action taken to reduce aircraft noise impact on communities and educate these communities regarding their aviation needs should eventually unlock many doors presently closed in the aviation community's face.

B. Action Needed

The diversity of pressure exerted upon the aviation community, particularly airport proprietors, has lead to a multiplicity of techniques for noise relief. Time restrictions, flight path restrictions. operational technique restrictions, and airport facility restrictions have been applied without any guidance other than the driving necessity to "do something," and this baffling array of procedures continues to grow. Faced with such complexity, the operator or pilot of an aircraft is forced to fall back on the choice of either proceding regardless of community imposed restrictions or using vaguely understood and thus ineffectual noise abatement improvisations.

There exists a pressing need for a uniform set of guidelines for effective noise abatement that can be explained to all impacted communities and used by all aircraft operators; these guidelines must be coupled with strenuous efforts to reduce aircraft noise through technological improvement so that the credibility of a centralized program is bolstered. An equally important need is that of boosting community awareness of the function of their airports and the relative importance of accessibility to air transportation.

Proliferation of local procedures and agreements can only bring about confusion diminution of safety through departure from standard procedures, and restrictions on system capacity. Central development, screening and implementation of noise abatement guidelines is mandatory if we are to avoid an increasingly complex and inefficient system. To put the matter in perspective, we must draw two comparisons:

- Inefficient aircraft and aircraft operators do not survive.
- The Continental Congress fell flat on its face when confronted by thirteen separate sets of commerce taxes, laws and restrictions — each promoted with intended disregard for the other.

II. CONCLUSIONS

The reluctance of the FAA to assume primacy in aircraft noise abatement issues is understandable due to the potential of this issue for litigation; however, this lapse in assertion is regrettable in that it forces airport and aircraft operators to suffer for providing community services. It is essential that the Federal government's aviation arm, the Federal Aviation Administration, assume responsibility for providing sane noise abatement guidelines, for developing effective noise reduction mechanisms, and for involving communities in the problem solving process.

III. RECOMMENDATIONS

Several recommendations can be made which would be consistent with the preceding discussion and which would serve to point noise abatement trends away from a conflict with air transportation system capacity:

A. Cost-Benefit Analysis

The FAA should institute a cost-benefit analysis, of national scope, that would attach quantitative value to the services rendered and expected of the air transportation system. As part of this analysis, the impact of noise abatement constraints should be analysed for future educational use and surveys should be made of sample communities that can serve as case studies in costs and benefits of air transportation. Inclusion of such opposing quantities as business generated vs. property value lost is vital if the studies are to have meaning to people at the community level.

B. Operational Techniques

The FAA should carefully review all potential noise abatement operational techniques and establish a uniform recommendation. Further, when procedures such as a uniform departure profile and traffic dispersion offer advantages for system capacity while reducing community noise, these procedures should be strongly encouraged.

C. Land Use Controls

The FAA should increase its efforts to rationalize land use in areas impacted by aircraft noise and to promote comprehensive zoning as well as insulation of buildings. Coordination with other Federal agencies will be required as will close contact with state and local governments.

D. Community Involvement

FAA area offices should initiate local study groups that would draw from diverse segments of local communities and which could serve as contact points — at the lowest level — between the recipients of aircraft noise, the representatives of aircraft operators, and those who are attempting to develop technological improvements which will minimize aircraft noise.

In case of this latter recommendation, it is particularly important for the FAA to disseminate information that does not unfairly boost expectations regarding the degree of relief available to noise impacted areas.

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Chapter III

APPENDICES

FREEDOM OF AIRSPACE
Topic Group 3

APPENDIX A

The following is the status of all existing special use airspace designated as of July 1978:

SPECIAL USE AIRSPACE AS OF JULY 13, 1978

Restricted Areas:

	Total number	Number joint use	Total sq. mi.	Percent of sq. mi. made joint use	Percent of total land area designated as restricted area
The 48 states	273	250	75,731	88.42%	2.49%
Alaska	9	6	1,387	79.81%	.24%
Hawaii	10	10	446	100.00%	6.96%
Guam	1	0	37	0	18.23%
Puerto Rico	4	4	149	100.00%	4.35%

Restricted areas are designated to confine or segregate activities considered hazardous to nonparticipating aircraft. The areas are described in Part 73 of the Federal Aviation Regulations and include lateral and vertical boundaries, time of designation, the military organization for which the area was designated and, if designated joint use, the FAA organization authorized to control that airspace when the using agency has released it back to the FAA.

Presently there are 273 restricted areas in the 48 conterminous states encompassing 75,731 square statute miles within the national airspace. Of this total, 250 are joint use and therefore available to all civil and military aviation when not required to contain the activity for which designated. Of the total of 75,731 square miles of restricted area airspace, 66,762 square miles are joint use and 8,969 square miles are nonjoint use. Of the 8,969 square miles of nonjoint use airspace, 8,021 square miles comprise four restricted areas as follows: R-4807 Nellis AFB, R-4808N ERDA, R-4809 ERDA, and R-5107B White Sands. The other nonjoint use are small with 13 of them comprising 5 square miles, or less.

In accordance with Part 73 of the Federal Aviation Regulations, the using agency is required to provide the FAA with an annual use report for each area. The report covers the period from October 1 through the following September 30 and contains a detailed account of the actual usage made of the restricted area

during that time. The reports are reviewed by the FAA headquarters and regional offices to determine if the use is sufficient to warrant retention. If use is insufficient and the using agency cannot provide additional justification for the area, action is taken to revoke or reduce the area.

As a matter of interest, 143,678 square miles of restricted area airspace were designated within the 48 conterminous states on June 1, 1959, and 78,899 square miles in July of 1977. Comparing these figures with the present area shows a reduction of 67,947 square miles or more than a 47% reduction since 1959, ano a reduction of 3,168 square miles or a 4% reduction during the past 12 months.

Warning areas[1/]:	Number	Square miles
Adjacent to 48 states	82	338,165
Adjacent to Alaska	1	2,134
Adjacent to Hawaii	11	72,411
Adjacent to Guam	1	11,621
Adjacent to Puerto Rico	14	19,452
Adjacent to Panama	4	4,049

Military Operations Areas:

	Total number	Total sq. mi.	Percent of total land area established as MOA
The 48 states	225	354,524	11.67%
Alaska	6	41,512	7.27%
Hawaii	0		
Guam	0		
Puerto Rico	3	523	15.28%

Military Operations Areas (MOAs) are established to identify areas where military training, such as air combat maneuvers and aerobatics are conducted. Prior to inauguration of the MOA program, this type training was conducted in chartered ISJTAs and in unchartered ATCAAs. At that time, nonparticipating VFR pilots would fly unknowingly into ATCAAs where military training activities were being conducted. Now the areas are charted as MOAs and are activated only during actual times of use. VFR pilots may obtain general advisory information from neighboring flight service stations as to whether the MOA is active. The actual delivery of ordnance, whether air-to-ground or air-to-air, is conducted only within restricted areas or warning area - not in MOAs. Flight within MOAs is optional for VFR operations. More than normal vigilance should be exercised while transiting the area. VFR aircraft may transit or operate within an active MOA

[1/] Warning areas are established to contain hazardous operations conducted in international airspace by U.S. military forces. The activities conducted within warning areas may be as hazardous as those contained within restricted areas. Warning areas are depicted on aeronautical charts to alert nonparticipants to the existence of possible hazardous conditions. Controlling and scheduling agencies for the areas listed on the appropriate flight information charts and may also be obtained from the ARTCC's and FSS's.

without communications requirement or restriction of any kind. IFR aircraft are provided IFR separation through the MOA, or are cleared to circumnavigate the area. The Air Force has been granted an exemption from the provisions of FAR 91.71(c) (aerobatic rule) to the extent necessary to allow aerobatic manuevers to be conducted on airways within MOAs. However, due to the nature of their training requirements, certain Air Force units cannot apply the exemption, and some airways will therefore continue to be capped or part-timed.

Prohibited Areas:

	Total number	Total square miles
The 48 states	6	37

Alert Areas:

	Total number	Total square miles	Percent of total land area established as Alert Areas
The 48 states	28	24,814	.82%
Alaska	1	3,324	.58%
Hawaii	1	96	1.50%

EXAMPLES OF RESTRICTED AREAS

	Square miles state Land Mass	Square miles of Restricted Areas in States	% of State Restricted Area
California	158,693	24,144	15.2%
California minus R-2508 (Edwards)		8,006	5.0%
New Mexico	121,666	12,243	10.1%
Utah	84,916	6,382	7.5%
Nevada	110,540	8,202	7.4%
Arizona	113,909	7,270	6.4%
All other states	3,040,888	22,527	0.74%

The number of square miles of MOAs overlying the land mass have not been computed to date, since there are 24-controversial ones still in the planning state. It is estimated that the total number will be about 240 when all are designated, comprising approximately 15% of the total land mass. As per paragraph 804, 7400.2B, they will be reviewed periodically to justify their retention.

APPENDIX B

Documents Relating to the Management of Airspace

"Airmen's Information Manual" (B-1)

The following pages are from the August 1976 edition of the "Airmen's Information Manual, Part I". This is the most recent published definition of how the airspace is structured. It is presented here for reference purposes, as well as to establish the idea that the United States does not have a lot of unused airspace lying around to experiment with.

Chapter 2. AIRSPACE

Airspace users' operations and needs are varied. Because of the nature of some opertions, restrictions must be placed upon others for safety reasons. The complexity or density of aircraft movements in other airspace areas may result in additional aircraft and pilot requirements for operation within such airspace. It is of the utmost importance that pilots be familiar with the operational requirements for the various airspace segments.

UNCONTROLLED AIRSPACE

GENERAL

Uncontrolled airspace is that portion of the airspace that has not been designated as continental control area, control area, control zone, terminal control area, or transition area and within which ATC has neither the authority nor the responsibility for exercising control over air traffic.

VFR REQUIREMENTS

Rules governing VFR flight have been adopted to assist the pilot in meeting his responsibility to see and avoid other aircraft. Minimum weather conditions and distance from clouds required for VFR flight are contained in these rules. (FAR 91.105.) See figure 2-1.

IFR REQUIREMENTS

Federal Aviation Regulations specify the pilot and aircraft equipment requirements for IFR flight. Pilots are reminded that in addition to the altitude/flight level indicated in the table, FAR 91.119 includes a requirement to remain at least 1,000 feet (2,000 feet in designated mountainous terrain) above the highest obstacle within a horizontal distance of 5 statute miles from the course to be flown. The appropriate altitude/flight level for IFR flight in uncontrolled airspace is shown in figure 2-2.

ALTITUDE	UNCONTROLLED AIRSPACE		CONTROLLED AIRSPACE	
	Flight Visibility	Distance From Clouds	** Flight Visibility	** Distance From Clouds
1200' or less above the surface, regardless of MSL Altitude	*1 statute mile	Clear of clouds	3 statute miles	500' below 1000' above 2000' horizontal
More than 1200' above the surface, but less than 10,000' MSL	1 statute mile	500' below 1000' above 2000' horizontal	3 statute miles	500' below 1000' above 2000' horizontal
More than 1200' above the surface and at or above 10,000' MSL	5 statute miles	1000' below 1000' above 1 statute mile horizontal	5 statute miles	1000' below 1000' above 1 statute mile horizontal

* Helicopters may operate with less than 1 mile visibility, outside controlled airspace at 1200 feet or less above the surface, provided they are operated at a speed that allows the pilot adequate opportunity to see any air traffic or obstructions in time to avoid collisions.

** In addition, when operating within a control zone beneath a ceiling, the ceiling must not be less than 1000'. If the pilot intends to land or takeoff or enter a traffic pattern within a control zone, the ground visibility must be at least 3 miles at that airport. If ground visibility is not reported at the airport, 3 miles flight visibility is required. (FAR 91.105)

Figure 2-1—MINIMUM VISIBILITY AND DISTANCE FROM CLOUDS—VFR

CONTROLLED AND UNCONTROLLED AIRSPACE VFR ALTITUDES AND FLIGHT LEVELS			
If your magnetic course (ground track) is	More than 3000' above the surface but below 18,000' MSL fly	Above 18,000' MSL to FL 290 (except within Positive Control Area, FAR 71.193) fly	Above FL 290 (except within Positive Control Area, FAR 71.193) fly 4000' intervals
0° to 179°	Odd thousands, MSL, plus 500' (3500, 5500, 7500, etc)	Odd Flight Levels plus 500' (FL 195, 215, 235, etc)	Beginning at FL 300 (FL 300, 340, 380, etc)
180° to 359°	Even thousands, MSL, plus 500' (4500, 6500, 8500, etc)	Even Flight Levels plus 500' (FL 185, FL 205, 225, etc)	Beginning at FL 320 (FL 320, 360, 400, etc)

UNCONTROLLED AIRSPACE – IFR ALTITUDES AND FLIGHT LEVELS			
If your magnetic course (ground track) is	Below 18,000' MSL, fly	At or above 18,000' MSL but below FL 290, fly	At or above FL 290, fly 4000' intervals
0° to 179°	Odd thousands, MSL, (3000, 5000, 7000, etc)	Odd Flight Levels, FL 190, 210, 230, etc)	Beginning at FL 290, (FL 290, 330, 370, etc)
180° to 359°	Even thousands, MSL, (2000, 4000, 6000, etc)	Even Flight Levels (FL 180, 200, 220, etc)	Beginning at FL 310, (FL 310, 350, 390, etc)

Figure 2–2—ALTITUDES AND FLIGHT LEVELS

CONTROLLED AIRSPACE

GENERAL

Controlled airspace consists of those areas designated as Continental Control Area, Control Area, Control Zones, Terminal Control Areas and Transition Areas, within which some or all aircraft may be subject to Air Traffic Control. Safety, users' needs, and volume of flight operations are some of the factors considered in the designation of controlled airspace. When so designated, the airspace is supported by ground/air communications, navigation aids, and air traffic services.

CONTINENTAL CONTROL AREA

The continental control area consists of the airspace of the 48 contiguous States, the District of Columbia and Alaska, excluding the Alaska peninsula west of Longitude 160°00'00''W, at and above 14,500 feet MSL, but does not include:

1. The airspace less than 1,500 feet above the surface of the earth; or

2. Prohibited and restricted areas, other than the restricted areas listed in FAR Part 71 Subpart D.

CONTROL AREAS

Control areas consist of the airspace designated as Colored Federal airways, VOR Federal airways, Additional Control Areas, and Control Area Extensions, but do not include the Continental Control Area. Unless otherwise designated, control areas also include the airspace between a segment of a main VOR airway and its associated alternate segments. The vertical extent of the various categories of airspace contained in control area is defined in FAR Part 71.

POSITIVE CONTROL AREA

Positive control area is airspace so designated in Part 71.193 of the Federal Aviation Regulations. This area includes specified airspace within the conterminous United States from 18,000 feet to and including FL600, excluding Santa Barbara Island, Farallon Island, and that portion south of latitude 25°04'N. In Alaska, it includes the airspace over the State of Alaska from 18,000 feet to and including FL600, but not including the airspace less than 1,500 feet above the surface of the earth and the Alaskan Peninsula west of longitude 160°00'W. Rules for operating in positive control area are found in FARs 91.97 and 91.24.

TRANSITION AREAS

1. Transition areas are designated to contain IFR operations in controlled airspace during portions of the terminal operation and while transitioning between the terminal and en route environment.

2. Controlled airspace extending upward from 700 feet or more above the surface when designated in conjunction with an airport for which an instrument approach procedure has been prescribed; or from 1,200 feet or more above the surface when designated in conjunction with airway route structures or segments. Unless specified otherwise, transition areas terminate at the base of overlying controlled airspace.

AIRSPACE

CONTROL ZONES

1. Controlled airspace which extends upward from the surface and terminates at the base of the continental control area. Control zones that do not underlie the continental control area have no upper limit. A control zone may include one or more airports and is normally a circular area within a radius of 5 statute miles and any extensions necessary to include instrument departure and arrival paths.

2. Control zones are depicted on charts (for example—on the sectional charts the zone is outlined by a broken blue line) and if a control zone is effective only during certain hours of the day, this fact will also be noted on the charts. A typical control zone is depicted in figure 2-3. (See SPECIAL VFR CLEARANCES in Chapter 3)

TERMINAL CONTROL AREA

A Terminal Control Area (TCA) consists of controlled airspace extending upward from the surface or higher to specified altitudes, within which *all aircraft* are subject to operating rules and pilot and equipment requirements specified in Part 91 of the FAR's. TCA's are described in Part 71 of the FAR's. Each such location is designated as a Group I or Group II terminal control area, and includes at least one primary airport around which the TCA is located. (See FAR 71.12)

1. Group I terminal control areas represent some of the busiest locations in terms of aircraft operations and passengers carried, and it is necessary for safety reasons to have stricter requirements for operation within Group I TCA's. (See Far 91.70(c) and FAR 91.90)

2. Group II terminal control areas represent less busy locations, and though safety dictates some pilot and equipment requirements, they are not as stringent as those for Group I locations. (See FAR 91.70(c) and FAR 91.90)

3. Terminal Control Areas are charted on Sectional, World Aeronautical, En Route Low Altitude, DOD Flip and TCA charts.

The following areas have been designated as Group I Terminal Control Areas and are depicted on VFR Terminal Area Charts.

Atlanta	Miami
Boston	New York
Chicago	San Francisco
Dallas	Washington, D.C.
Los Angeles	

The following areas have been designated as Group II Terminal Control Areas and are depicted on VFR Terminal Area Charts.

Cleveland	Minneapolis
Denver	New Orleans
Detroit	Philadelphia
Houston	Pittsburgh
Kansas City	Seattle
Las Vegas	St. Louis

IFR ALTITUDES/FLIGHT LEVELS

Pilots operating IFR within controlled airspace will fly at an altitude/flight level assigned by ATC. When operating IFR within controlled airspace with an altitude assignment of "VFR-ON-TOP", flight is to be conducted at an appropriate VFR altitude which is not below the minimum IFR altitude for the route. See figure 2-2 (FAR 91.121) VFR-ON-TOP is not permitted in certain airspace such as positive control airspace, certain Restricted Areas, etc. Consequently, IFR flights operating VFR-ON-TOP will avoid such airspace.

VFR REQUIREMENTS

Minimum flight visibility and distance from clouds have been prescribed for VFR operation in controlled airspace. See figure 2-1. In addition, appropriate altitudes/flight levels for VFR flight in controlled, as well as in uncontrolled airspace have been prescribed in FAR 91.109. See figure 2-2. The ever increasing speeds of aircraft results in increasing closure rates for opposite direction aircraft. This means that there is less time for pilots to see each other and react to avoid each other. By adhering to the altitude/flight level appropriate for the direction of flight, a "built-in" vertical separation is available for the pilots.

SPECIAL USE AIRSPACE

GENERAL

Special use airspace consists of that airspace wherein activities must be confined because of their nature, or wherein limitations are imposed upon aircraft operations that are not a part of those activities, or both. These areas are depicted on aeronautical charts.

PROHIBITED AREA

Prohibited areas contain airspace of defined dimensions identified by an area on the surface of the earth within which the flight of aircraft is prohibited. Such areas are established for security or other reasons associated with the national welfare. These areas are published in the Federal Register and depicted on aeronautical charts.

RESTRICTED AREA

Restricted areas contain airspace identified by an area on the surface of the earth within which the flight of aircraft, while not wholly prohibited, is subject to restrictions. Activities within these areas must be confined because of their nature or limitations imposed upon aircraft operations that are not a part of those activities or both. Restricted areas denote the existence of unusual often invisible, hazards to aircraft such as artillery firing, aerial gunnery, or guided missiles. Penetration of restricted areas without authorization from the using or controlling agency may be extremely hazardous to the aircraft and its occupants. Restricted areas are published in the Federal Register and constitute Part 73 of the Federal Aviation Regulations. (See OPERATION IN RESTRICTED AIRSPACE in Chapter 3.)

WARNING AREA

Warning areas are airspace which may contain hazards to nonparticipating aircraft in international airspace. Warning areas are established beyond the 3 mile limit. Though the activities conducted within warning areas may be as hazardous as those in Restricted areas, Warning areas cannot be legally designated because they are over international waters. Penetration of Warning areas during periods of activity may be hazardous to the aircraft and its occupants. Official descriptions of Warning areas may be obtained on request to the FAA, Washington, D.C.

AIRSPACE

MILITARY OPERATIONS AREAS (MOA)

Military Operations Areas consist of airspace of defined vertical and lateral limits established for the purpose of separating certain military training activities from IFR traffic. Whenever an MOA is being used, nonparticipating IFR traffic may be cleared through an MOA if IFR separation can be provided by ATC. Otherwise, ATC will reroute or restrict nonparticipating IFR traffic.

Some training activities may necessitate acrobatic maneuvers, and the USAF is exempted from the regulation prohibiting acrobatic flight on airways within MOAs.

Pilots operating under VFR should exercise extreme caution while flying within an MOA when military activity is being conducted. Information regarding activity in MOA's may be obtained from any FSS within 200 miles of the area.

These areas will be depicted on Sectional, VFR Terminal and Low Altitude En Route Charts.

ALERT AREA

Alert areas are depicted on aeronautical charts to inform nonparticipating pilots of areas that may contain a high volume of pilot training or an unusual type of aerial activity. Pilots should be particularly alert when flying in these areas. All activity with an Alert Area shall be conducted in accordance with Federal Aviation Regulations, without waiver, and pilots of participating aircraft as well as pilots transiting the area shall be equally responsible for collision avoidance. Information concerning these areas may be obtained upon request to the FAA, Washington, D.C.

OTHER AIRSPACE AREAS

AIRPORT TRAFFIC AREAS

1. Unless otherwise specifically designated (FAR Part 93), that airspace within a horizontal radius of five statute miles from the geographical center of any airport at which a control tower is operating, extending from the surface up to, but not including, an altitude of 3,000 feet above the elevation of the airport.

2. The rules prescribed for airport traffic areas are established in FAR 91.70, 91.85 and 91.87. They require, in effect, that unless a pilot is landing or taking off from an airport within the airport traffic area, he must avoid the area unless otherwise authorized by ATC (either directly from the ATC facility responsible for the Airport Traffic Area, or from a facility from which the pilot is receiving radar services). If operating to, from or on the airport served by the control tower, he must also establish and maintain radio communications with the tower. Maximum indicated airspeeds are prescribed. Airport traffic areas are indicated on sectional charts by the blue airport symbol, but the actual boundary is not depicted. See figure 2-3.

AIRPORT ADVISORY AREA

1. The area within five statute miles of an airport where a control tower is not operating but where a Flight Service Station is located. At such locations, the FSS provides advisory service to arriving and departing aircraft. (See AIRPORT ADVISORIES AT NON TOWER AIRPORTS in Chapter 3.)

2. It is not mandatory that pilots participate in the airport advisory service program, but it is strongly recommended that they do.

MILITARY TRAINING ROUTES

Military Training Routes (MTR) program is a joint venture by the Federal Aviation Administration (FAA) and the Department of Defense (DOD) in that the routes are mutually developed for use by the military for the purpose of conducting low-altitude high speed training. The routes are flown, to the maximum extent possible, under IFR flight rules and published on appropriate aeronautical charts. Generally, MTRs are established below 10,000 feet MSL for operations at speeds in excess of 250 KTS. However, route segments may be defined at higher altitudes for purposes of route continuity. For example, route segments may be defined for descent, climbout, and mountainous terrain. There are IFR and VFR routes as follows:

1. IFR Military Training Routes—IR

Operations on these routes are conducted in accordance with instrument flight rules regardless of weather conditions. Published hours of operations for each route will be depicted on appropriate IFR and VFR charts. Current information concerning the route utilization is available from the appropriate ATC facility or flight service stations (FSSs) within 200 miles of the route.

2. *VFR Military Training Routes—VR*

Operations on these routes are conducted in accordance with visual flight rules. Normal hours of operations for each route will be depicted on appropriate VFR charts. Variations from the published hours and more specific data concerning the route utilization are available from the FSSs within 200 miles of the route.

3. VFR Low-Altitude Training Routes—TR

Operations on these routes, exclusive of takeoff and landing, are conducted at or below 1,500 feet above the surface at speeds in excess of 250 IAS and under VFR flight rules. There are to be no 'new' TR routes; all TR routes will be converted to IR and VR routes by January 1, 1979. Current information concerning the route utilization is available from FSSs within 200 miles of the route.

The DOD, Flight Information Publication, Section AP/1B, (Area Planning, Military Training Routes—U.S.) contains a narrative description of these routes and includes charts depicting both the VFR and IFR Military Training Routes and VFR Low-Altitude Training Routes VR/IR/TR. This publication is available to the general public by single copy or annual subscription from the National Ocean Survey, Distribution Division, C-44 Riverdale, Maryland 20840. This DOD FLIP, including charts, is available for pilot briefings at every FAA-FSS and at many airports.

ALL WEATHER LOW ALTITUDE TRAINING ROUTES (OLIVE BRANCH ROUTES)

Olive Branch Routes are somewhat similar to VFR Low Level Routes but may extend to higher altitudes and are conducted under both VFR and IFR weather conditions. Further information on Olive Branch Routes

is available in the publication Graphic Notices and Supplemental Data and from the same sources listed above under Military Training Routes.

TEMPORARY FLIGHT RESTRICTIONS

1. Temporary flight restrictions may be put into effect in the vicinity of any incident or event which by its nature may generate such a high degree of public interest that the likelihood of a hazardous congestion of air traffic exists. FAR 91.91, as amended 1 March, 1971, prohibits the operation of nonessential aircraft in airspace that has been designated in a NOTAM as an area within which temporary flight restrictions apply. The revised rule will continue to be implemented in the case of disasters of substantial magnitude. It will also be implemented as necessary in the case of demonstrations, riots, and other civil disturbances, as well as major sporting events, parades, pageants, and similar functions which are likely to attract large crowds and encouraging viewing from the air.

2. NOTAM's implementing temporary flight restrictions will contain a description of the area in which the restrictions apply. Normally the area will include the airspace below 2,000 feet above the surface within 5 miles of the site of the incident. However, the exact dimensions will be included in the NOTAM.

3. Pilots are not to operate aircraft within such an area described in the NOTAM unless they are one of the following: (1) That aircraft is participating in disaster relief activities and is being operated under the direction of the agency responsible for relief activities; (2) They are operating to or from an airport within the area and such operation will not hamper or endanger relief activities; (3) Their operation is authorized under an IFR ATC clearance; (4) Flight around the area is impracticable because of weather or other considerations and advance notice is given to the Air Traffic facility specified in the NOTAM, and enroute flight through the area will not hamper or endanger relief activities; or (5) They are carrying accredited news representatives or persons on official business concerning the incident, and the flight is conducted in accordance with FAR 91.79 and a flight plan is filed with the Air Traffic facility specified in the NOTAM.

Summary of Controlled Visual Flight Proposal (B-2)

A summary of the concept of controlled visual flight in mid-altitude airspace. This document was presented to Topic Group 3 as a fairly well coordinated concept within the FAA, but one which was still engaged in the process of approval and had not been issued as an Advance Notice of Proposed Rule-Making.

The FAA currently has a Notice of Proposed Rule-Making (NPRM) in the works to permit a form of "Controlled Visual Flight" (CVF) in airspace between 12,500 to 18,000 feet. This concept will allow VFR aircraft to continue to fly in these altitudes but will require them to be in communication with the nearest Air Traffic Control (ATC) facility so that separation between all aircraft can be provided. Additionally, there is a plan being developed to raise the ceilings of Terminal Control Areas (TCA) to 12,500 feet and possibly raise the speed restriction floor from 10,000 feet to 12,500 feet. These plans will provide a standard demarcation altitude for all requirements.

It would appear that the ATC System is capable of handling CVF operations within the en route environment. However, should we introduce these operations, the agency has no way, at this time, of categorically stating that they can be handled without impact upon the ATC system.

Current regulations require that all aircraft be equipped with a Mode 3/A 4096 Radar Beacon Transponder with automatic pressure altitude reporting equipment above 12,500 feet MSL. At present, oxygen is required above 12,500 feet.

Positive Control Areas (PCA) are planned to be lowered to 12,500 feet from the current 18,000 feet to permit for a Controlled Visual Flight (CVF) concept.

Past studies have indicated that a controlled VFR/IFR environment can be compatible, provided all aircraft are in contact with ATC.

Airspace Structuring

At the present, FAA proposes to (1) lower the PCA to 12,500 feet MSL; and (2) eliminate Continental Control Area below 60,000 feet MSL.

Controlled visual flights would be permitted within this strata, but PCA above 18,000 feet MSL will remain as presently regulated - no VFR.

No new equipment is required for this concept.

Flight Plans must be filed under this program so that ATC can pre-plan their traffic - both VFR and IFR.

A CVF pilot may be required to accept and execute altitude assignments, routings, and radar vectors.

Altitude assignments will be required, but the concept will be structured so that the same visibility and distance from cloud criteria currently in effect for VFR flight will be required.

Pilot Requirements

The planned establishment of CVF procedures providing ATC services for visual operations requires a degree of pilot proficiency.

The pilot operating CVF will require sufficient proficiency to receive and comply with ATC instruction.

An IFR rating is not envisioned as a requirement. The requirements would essentially remain the same as required for TCAs (FAR 91.90).

Notes on Controlled Visual Flight (B-3)

A landmark presentation on electronic VFR was made to Topic Group 3 in July 1978. The result of that presentation was a better understanding of the technical and operational considerations of this concept. While technical feasibility seemed achievable, and while operational utilization in a completely equipped community of users was conceivable, the Group was badly frustrated with the implementation dilemma.

Working Paper
TG-3

12 July 1978

ELECTRONIC VFR

Questions and Issues

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ELECTRONIC VFR

What is it?

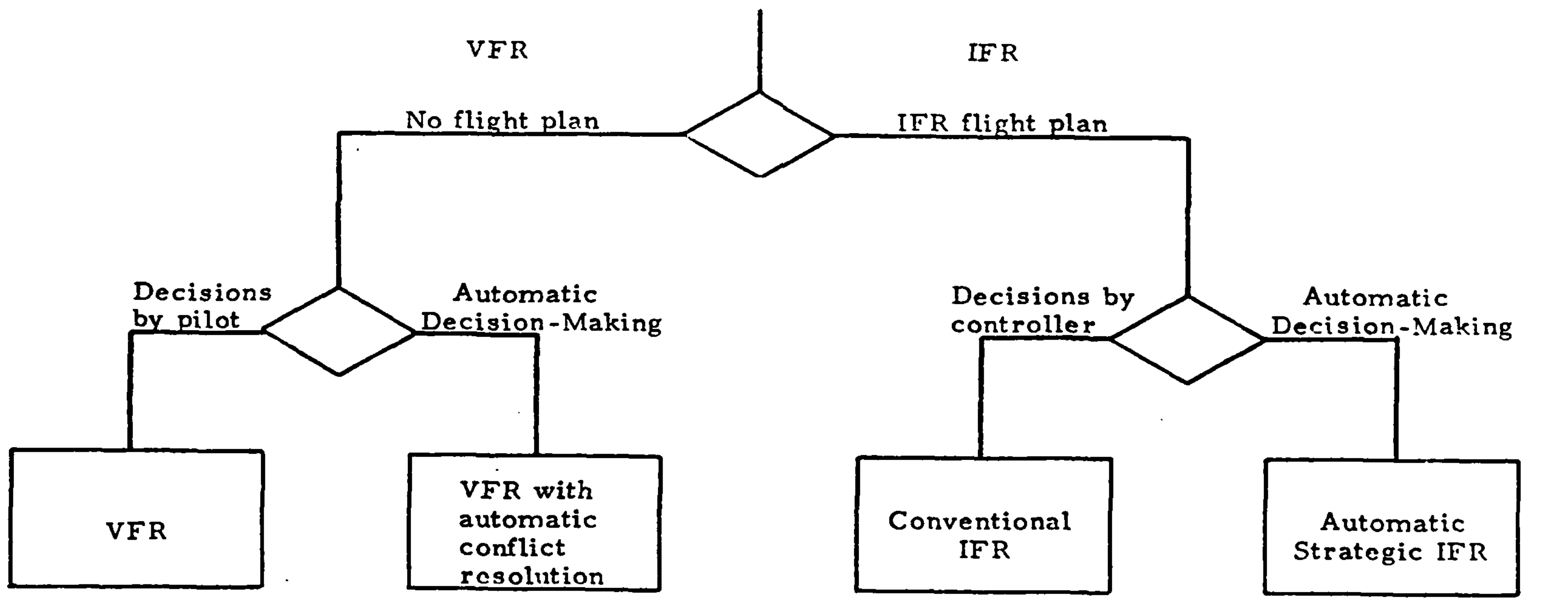
Uncontrolled operation of aircraft in instrument meteorological conditions

Uncontrolled means: no flight plan
no interaction with a controller

In other words, the aircraft is operated according to the same (or similar) rules used today for VFR operation outside of controlled airspace, *except*, rather than separation by see-and-be-seen, some combination of ground-based and airborne electronics provides the pilot with the information he needs to maintain safe separation from other aircraft.

ELECTRONIC VFR

Classification of ATC Modes



ELECTRONIC VFR

Where might it be useful?

Principally envisioned for low-altitude (<12,500' MSL) en route airspace

Possibly uncontrolled terminals

Possibly mid-altitude (12,500' - 18,000')

Back-up role only in high-altitude positive control airspace

ELECTRONIC VFR

Why are we talking about it?

Reduce ATC system costs by minimizing or halting the increase in the number of controllers which will be required to handle the projected traffic growth.

Increase operational flexibility and reduce costs through the elimination of IFR routing constraints and attendant delays

ELECTRONIC VFR

How do we do it?

One of the following, or a combination of them

- Provide the pilot with information on proximate traffic which might pose a collision threat
- Provide the pilot with automatically-generated maneuver instructions to prevent or resolve conflicts

ELECTRONIC VFR

Operational Issues

Can electronic VFR operate in the same airspace as conventional IFR:

(a) Where radar coverage exists?
(b) Where radar coverage doesn't exist?

How is electronic VFR implemented operationally?

Is the transition period (i.e., mixed electronic VFR and conventional IFR) a temporary or permanent situation?

If permanent (i.e., conventional IFR is never completely phased out in any airspace), have we lost a major benefit of electronic VFR?

How does the electronic VFR aircraft enter and exit controlled airspace such as TCAs, TRSAs?

How are IMC approaches and departures accommodated at uncontrolled airports?

> If this requires reversion to conventional procedural IFR, have we lost the game?

In what sort of traffic densities can the system operate?

> What happens if these are exceeded?

Is electronic VFR worthwhile if limited to airspace where ground-based radar coverage exists?

What are the tradeoffs between the need for ground surveillance, permissible traffic density, and avionics cost?

What are the failure modes, and what kinds of backups are required to maintain an adequate level of safety?

ELECTRONIC VFR

Safety Issues

What level of safety (collision protection) must the system achieve -- that of VFR or that of IFR? If that of VFR is permissible, must there also be a more protected (IFR?) mode?

Will electronic VFR encourage unqualified pilots to exceed their limitations?

Must the system provide additional services such as:

- Terrain avoidance?
- Weather avoidance?

ELECTRONIC VFR

Technical Issues

Ground system and avionics cost

Equipage requirements

Capacity / Saturation

Need to accommodate terrain, weather situation in resolving conflicts

Failure modes

Implementability

Ability to accommodate unequipped aircraft

ELECTRONIC VFR

Alternative Technical Approaches

Surveillance

- DABS
- Synchro-DABS
- ACAS
- BCAS
- Broadcast GPS-derived position

Conflict Resolution

- Pilot based - CDTI
  - Ground derived
  - Air derived
- Hardware generated
  - Ground vs air computed
  - Vertical vs horizontal/vertical resolution

ELECTRONIC VFR

What next?

Quantify benefits

Determine potential regions of operation

Select, or at least narrow choice of, technical approach

Electronic VFR Questions and Issues (B-4)

Dr. Thomas Amlie of FAA's Office of System Engineering Management was a persistent participant and ardent advocate of simple collision avoidance technology. An example of his single-minded logical persuasion is included in these supporting documents because (a) it is one credible technical configuration, and (b) it is exemplary of the quality of working papers Topic Group 3 received from its "resource people".

Integrated Collision Avoidance System (ICAS)

Introduction

A proposal has been made for a collision avoidance system which deserves the consideration of the aviation community.

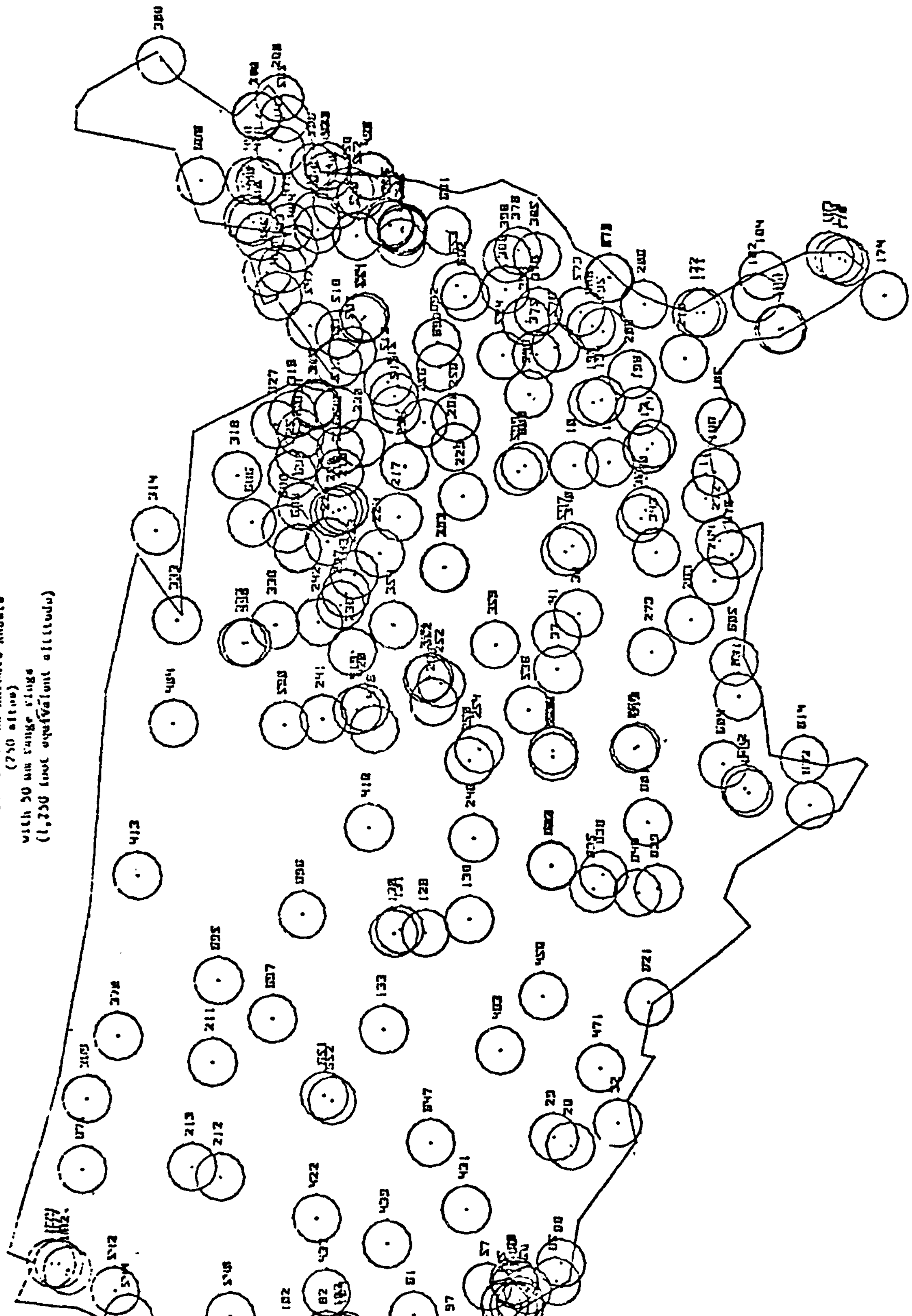
Background

The members of Topic Group 3 have been discussing a concept called "Electronic See-and-Avoid" (ESAA). In this concept, a pilot would be permitted to fly in IMC without a flight plan or without contact with ATC as long as he had a functioning Collision Avoidance Gadget (CAG) *on his aircraft*. The pilot would need an instrument rating and the aircraft would have to be equipped in accordance with FAR 91. This concept would apply in low-altitude airspace outside of TCA's, traffic zones of towered airports, and such busy transition airspace as the FAA might designate.

The discussion always gets back to the question of: What does this CAG do? How does it do it? How much does it cost? How are aircraft owners motivated to install it? Every time the discussion reaches this point, there arises the very real problem of transitioning from the present systems. The following points will summarize the CAG situation.

1. The DABS/ATARS will provide good separation assurance when DABS is finally installed. It will be 1995 or so before DABS is fully implemented and even then the coverage will be as shown in the attached figure. It will be seen that coverage will be good in almost all airspace where air carriers fly, and not very good in the low-altitude airspace where most of general aviation flies.

2. The Airborne Collision Avoidance Systems (ACAS) proposed by McDonnell-Douglas, RCA and Honeywell and tested by the ATA, Navy,



FAA Terminal and Enroute Radars
(750 sites)
with 50 nm range rings
(1,250 foot equivalent altitude)

Air Force and NAFEC showed that they could reliably prevent collisions between equipped aircraft. They used vertical escape maneuvers only and required the pilots to perform a 0.1 gravity maneuver.

3. If the CAG is to provide the primary separation assurance, the reliability must be very high. This implies, among other things, top and bottom antennas on both aircraft involved in an encounter.

4. The Beacon Collision Avoidance System (BCAS) has significant and disqualifying shortcomings for use as a primary separation CAG. BCAS is here taken to mean a system which uses the response of ATCRBS equipped aircraft to perform the CAG function.

   a. Active BCAS

   The BCAS as proposed by MITRE and built and tested by NAFEC interrogated nearby aircraft and listened for the responses, similar to the ground-based ATC surveillance system. The results were that if the BCAS aircraft was above the ATCRBS aircraft, it only got 70% of the tracks due to the top/bottom antenna problem. In addition, due to synchronous garble, it did not function well in the presence of many aircraft and thus would not work in the vicinity of a busy general aviation airport. It would also require Mode C encoders in all aircraft.

   b. Passive BCAS

   There have been various proposals to listen to the interrogations from the ground, listen to the responses from nearby aircraft and correlate these signals to determine the position and course of nearby aircraft. These schemes require that one be within line-of-sight and 60 miles of at least two ground-based interrogators and, further, that the geometry be favorable. Favorable geometry means that the relative bearing from the aircraft to the two ground-based interrogators should differ by approximately 90 degrees. That is, if one of the interrogators is north of you, the other should be east or west. Reference to the attached coverage charts will show that these conditions would not be met in most of the areas of the United States. Further, the passive BCAS suffers from the same synchronous garble problem as the active BCAS, although not quite as badly. The estimate is that the system would saturate in the top 30 terminals due to traffic density. Unfortunately, it is only in these terminals that the necessary low-altitude coverage would be available to allow the concept to function in the first place. All the flight test data available so far shows unacceptable performance.

c. Full BCAS

The FAA has just finished an exhaustive study on the BCAS problem. This study took into account the shortcomings discussed under (a) and (b), above, and addressed the question of how to make a BCAS that would work no matter what. The result was a credible, but extremely complex system that could cost $75,000-$100,000 each and would still require top and bottom antennas on all ATCRBS and DABS aircraft to get the required signal reliability.

d. Rationale for BCAS

Despite the fact that the BCAS would not have adequate reliability to provide primary separation assurance, it could provide a very useful backup capability, particularly for air carriers. It would function adequately in remote airspace, specifically over the North Atlantic. Preventing just one collision involving an air carrier is worth the price of admission.

Discussion

The basic problem always comes down to economics. The ATC system is, and will continue to be, predominantly ground based. A TSO'd ATCRBS transponder presently retails for approximately $600. The cost prediction studies made for FAA by ARINC indicated that a general aviation quality DABS with ATARS display would retail for about $1,200 and a general aviation quality ACAS would also retail for approximately $1,200. ATARS and CAS both require encoding of barometric altitude and the least expensive altitude encoders retail for around $800. Thus, the general aviation owner who wanted to fly in the ATC system and also wanted the ESAA option would be looking at a bill of $1,200 plus $1,200 plus $800, equalling $3,200 for DABS plus CAS, or $600 plus $1,200 plus $800 equalling $2,600 for ATCRBS plus CAS. In addition, the owner who bought the ATCRBS plus CAS would not get the ATARS function which would protect him against VFR ATCRBS aircraft which did not have a CAS. There is also the classic problem that the first owners who equipped with the CAS would not get much for their money because very few other aircraft were equipped.

A Proposed Solution

Dr. Ed Koenke of the Office of Systems Engineering Management (OSEM) of the FAA has suggested an interesting and potentially attractive method of getting around the problems listed above. This is to combine the functions of the CAS and the DABS into one box. It would be attractive if the incremental cost to add the CAS function to the DABS, or to add the DABS function to the CAS, was

reasonable and if the two functions could be put in the same equipment without interfering with each other.

The interference issue is examined subsequently and the conclusion is that there is no problem. Briefly, the proposal is to put an interrogate/respond CAS function at 1030 MHz, which is the same frequency as the ATCRBS/DABS interrogation from the ground. The format of the signal-in-space would be what the engineers at the Naval Air Development Center (NADC) recommended after extensive laboratory and flight test. The difference, of course, would be that the interrogate/respond function would be at 1030 MHz instead of at 1607.5 as orginally tested. This signalling format is known to be reliable even in the presence of a very high fruit rate. The DABS and the CAS would thus share a common antenna system, receivers, transmitter, power supply, case and display. It would be necessary to add the CAS digital logic to a DABS or the DABS digital logic to the CAS to make this multipurpose device. The advantages are obvious: it would function against suitably equipped aircraft when not in coverage of the ground based system and would also be compatible with the ground based system when within coverage. At present the term BCAS means many things to many people, so to avoid confusion, this device will arbitrarily be called the Integrated CAS or ICAS.

Assuming for the moment that the interference analysis is correct and that the functions are compatible, the question is, what does it cost?

Predicted Costs

This is a very difficult subject. The costs of general aviation avionics depend on the cost of the parts used to build them, but the costs of these parts change drastically with such factors as competition and the volume of production. In reviewing the 1975 ARINC cost study, it appears that the NARCO submission to ARINC was quite credible. Instead of performing a piece-parts analysis, NARCO compared the complexity and performance required of the CAS design with comparable equipment they were already building and selling -- presumably at a satisfactory profit. NARCO state that the retail price of the CAS would be approximately $1,000 (without altitude encoding) or $350 over the retail price of their TSO'd AT-50A ATCRBS transponder. This CAS cost prediction did include top and bottom antennas. The ICAS would be a little more expensive because the 1030 MHz transmitter would have to be more frequency-stable to permit use of the DABS 1030 MHz receiver without requiring a wider receiver bandwidth and thus derogating the DABS performance. It would also require the transmitter to work at both 1030 MHz and 1090 MHz so that it could perform both the ATCRBS/DABS and the CAS functions. To get this bandwidth implies a solid-state transmitter instead of the vacuum tube presently used in most ATCRBS designs. Present information is that the vacuum tube and cavity used as a transmitter presently

costs ATCRBS manufacturers about $30, and the parts required to build a solid-state transmitter are about $125. These transistor prices are expected to go down as sales volume increases. The DABS would accrue some gain in performance and reliability by having top and bottom antennas and a solid-state transmitter. The best guess at the moment is that adding the ICAS feature to the general aviation DABS transponder would add $400-$600 to the retail price. Similarly, and also just a guess, adding the DABS function to the ICAS would add $400-$600. Thus:

DABS	$1,200
ICAS	1,200
DABS + ICAS	$1,600-1,800
DABS + ICAS + Integral Altitude Encoding	$2,100-2,300

(Note: DABS means ATCRBS plus DABS)

More precise information would have to come from houses like NARCO, Bendix or Genave and could only come after a complete design was available. In addition, some alert manufacturer would probably observe that the case, chassis, plugs and cables, power supply and solid-state transmitter comprised about half of the bill of materials required for a solid-state DME. It would be reasonable and profitable to offer a single panel-mounted unit that had the ATCRBS/DABS/ Altitude Encoding/DME/ICAS functions built in. This would conserve panel space because the height of the ATARS proximity warning display takes up more space than the electronics behind it requires.

Summary

The ICAS concept appears to provide at least a partial solution to the problem of the high cost of general aviation electronic equipment. The key to implementation is to establish a stand-alone National Standard for the ICAS and make it optional so that users could buy whatever they wanted. Inasmuch as the DABS standard has already been published and agreed to internationally, it would be very disruptive to add an ICAS standard to it. Presumably the ICAS standard would include any protocol that might be necessary to prevent the ICAS from interfering with the DABS/ATCRBS. In this situation, an owner who was sure he was never going to join the ATC system in any way and didn't want the ATARS or other data link services, could buy the ICAS only ($1,700 with altitude encoding). Similarly, an owner who believes he was going to fly in DABS coverage at all times could buy the DABS only. Either of these two choices would be somewhat short-

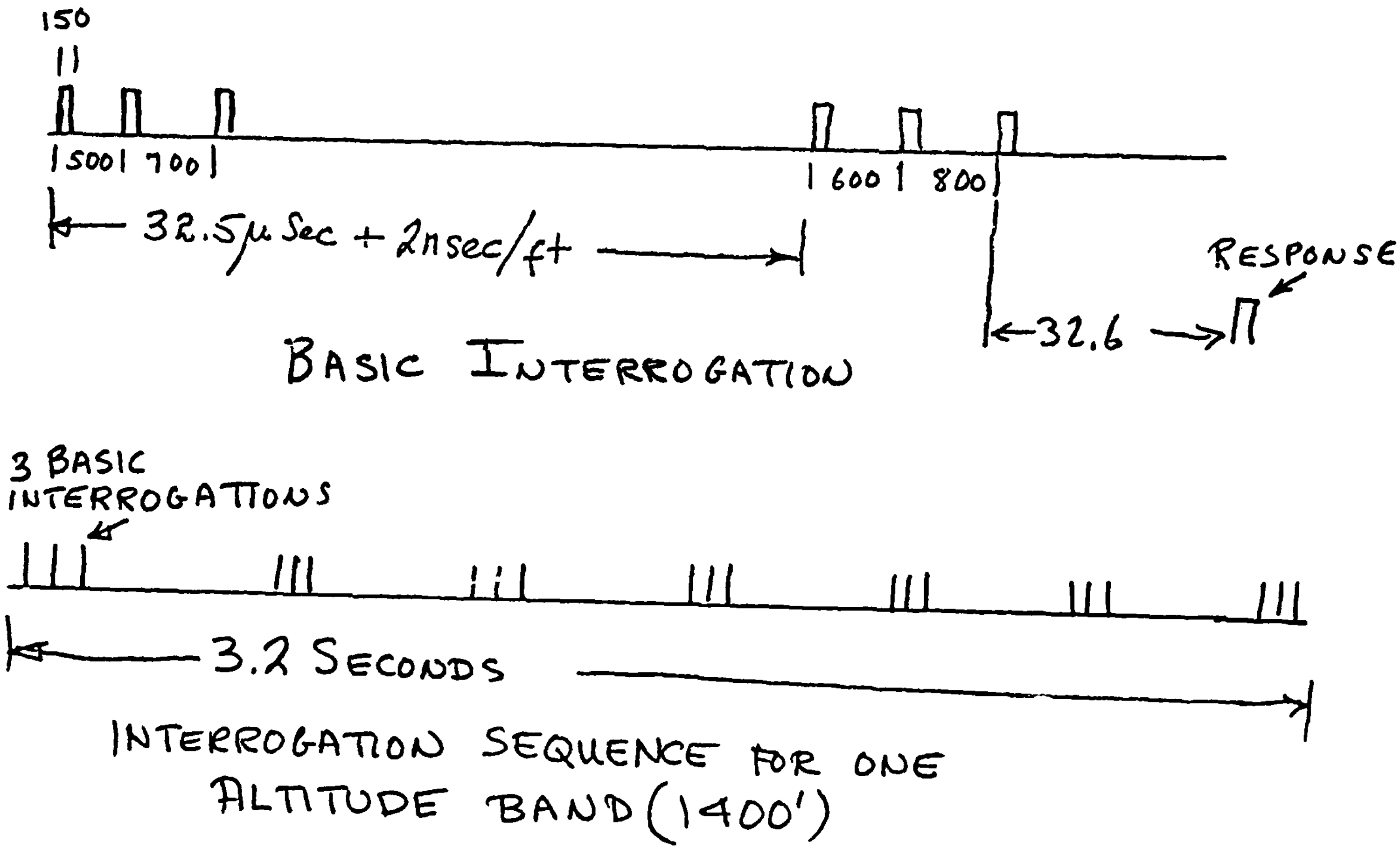
sighted and most owners would opt to buy the full package at approximately $2,200, including altitude encoding. Any owner who considered resale value would certainly come to this conclusion.

Interference Analysis

The signalling format recommended by the engineers at NADC at the conclusion of the FAA-sponsored ACAS test program is as shown in Figure 1. The basic interrogation is a triplet of 150 nano-second pulses followed by a delay of 32.5 micro-seconds, plus an added delay of 2 nano-seconds per foot to define the altitude band being interrogated. At the end of this delay a similar, but different, triplet is transmitted. Any equipped aircraft that receives this interrogation and that is within 700 feet of the altitude described by the interrogation will answer with a single pulse at the same frequency. Each CAS full interrogation is comprised of three of the basic interrogations just described. This provides better link reliability and allows for defruiting. Each CAS interrogates the airspace just above it with seven full interrogations every three seconds, and the airspace just below it with seven full interrogations every three seconds. If it detects a possible threat, it adjusts the altitude band interrogated to refine the measurement of the threat altitude.

Before analysis of the interference effect of the ICAS on the DABS, it is necessary to know what kind of signals could affect the DABS. Lincoln Laboratory states that a 150 nano-second pulse at 1030 MHz would have to be at least 6db stronger than the DABS interrogation to have any effect at all. The ATCRBS is in even better shape because the uplink message consists only of two 0.8 micro-second pulses spaced at either 8 micro-seconds (Mode A) or 21 micro-seconds (Mode C). The noise spike rejection circuits in the ATCRGBS reject narrow pulses and keep them out of the decoding circuits. A very strong 150 nano-second pulse might desensitize the transponder for a few micro-seconds due to action on the "ditch-digger" circuits.

To get a handle on the problem, assume an absurb case. Assume an aircraft density of 0.2 aircraft per square mile (very high) and that all aircraft in the area are flying in an altitude stratum only 700 feet thick. The air-to-air communication range of the ICAS, assuming 100 watt transmitter, reasonable losses and -71 dbm MTL, would be about 10 miles. Let us examine what happens to one aircraft in this situation, assuming all are ICAS equipped. There are 63 aircraft within 10 miles of this aircraft, all with the 700 foot altitude stratum. Each one generates 14 interrogations per second and 7 times 63 equals 441 responses. The aircraft being analyzed thus receives 14 times 63 equals 882 interrogations and 441 times 63 equals 27,783 responses per second in the ICAS mode. The question then is: How many of these responses could interfere with a DABS interrogation, assuming the 6 db criterion mentioned above? Assume that this aircraft is 50 miles from a DABS



150
500
700
600
800
32.5μ Sec + 2nsec/ft
RESPONSE
32.6
BASIC INTERROGATION
3 BASIC INTERROGATIONS
3.2 SECONDS
INTERROGATION SEQUENCE FOR ONE ALTITUDE BAND (1400')

FIGURE 1

interrogator with 20 db antenna gain and a 200 watt transmitter, then an ICAS-equipped aircraft would have to be within two miles of this aircraft before it could possibly interfere. Assume that there are five such aircraft. This aircraft receives 5 times 14 equals 70 interrogations per second plus 5 times 441 equals 2,205 responses per second from these five aircraft. Each interrogation gives two opportunities to interfere, so there are 2 times 70 plus 2,205 equals 2,345 opportunities to interfere per second. A DABS uplink transmission is either 18 micro-seconds (short message) or 36 micro-seconds (large message). The short message will be much more common than the long one. Thus, the probability of an interference would be, roughly, 2,345 times 18 times 10^{-6} equals .0422 or 4 percent per interrogation. Inasmuch as the DABS automatically reinterrogates if the aircraft doesn't respond properly, it appears that there wouldn't be any problem even with this absurb aircraft density. The ATCRBS would be less affected than the DABS because the time window in which an interfering pulse could cause a problem is smaller than for DABS.

The effect of the DABS on the ICAS should also be examined. Assume a DABS ground station is tracking 3,600 aircraft spaced uniformly in azimuth. Assume the DABS has a 4 degree antenna beamwidth and a 4-second scan period. Assume the ICAS has been designed so that it recognizes a DABS interrogation and doesn't try to correlate it as an ICAS response. The DABS interrogation will, in general, be strong enough to block out ICAS responses. The DABS antenna is pointing at this aircraft 1/90th of the time and during the time it is pointing at the aircraft can block .07% of the interrogations and responses.

A Possible Transition Scenario (B-5)

As a thought starter, the Chairman floated a Strawman transition scenario before the September 1978 meeting of Topic Group 3. It did not receive overwhelmingly enthusiastic reception, but in retrospect it may have some helpful thoughts.

Alternate or Supplementary Airspace Management
(Assuming a Technically Feasible Traffic Avoidance Gadget - TAG)

1. Adopt modified controlled VFR rules for TCA airspace and airspace between 12,500 feet MSL and 18,000 feet MSL except 2,500 feet, or less, AGL. This will be in accordance with William Broadwater's concept paper on "Controlled Visual Flight", dated July 12, 1978.

2. Adopt DABS National Standard. Commit DABS implementation funds and schedule.

3. Supplement DABS National Standard with a separate National Standard for a Traffic Avoidance Gadget (TAG) symbiotic and synergetic with the DABS RF signal format, duty cycles, and power budget. Design TAG system for three nines reliability; zero interference with secondary radar surveillance system.

4. Develop benefits to provide incentive for equipping with DABS transponder. Expect competing transponder manufacturers to lead or, at least, complement DABS sensor installation schedule with "DABS compatible" transponder designs.

5. Develop incentive for operators in TCA and other airspace justifying control to carry DABS-TAG to supplement ATC separation with a redundant backup. Limit claims to three sixes system reliability. Concentrate on high exposure users of high density airspace - trunk carriers, regionals, commuters, etc.

6. Depending on success with (5.) above, competing general aviation DABS-TAG designs will be offered. System designed in (3.) above, will be tried and either proven or corrected to achieve three nines reliability and a "tolerable" false alarm rate, i.e:

   a. In VMC, no alarm without target.
   b. In VMC, no target without an alarm.
   c. With very few exceptions.
   d. For years.

7. Implement airspace designs to further unload the ATC system as justified by implementation progress in (5) and (6) above, remembering that number of airplanes equipped is good, but percent of exposure is better. Count the hours in high density airspace.

Thoughts on Electronic See and Avoid (B-6)

Another significant landmark paper in our deliberations was presented by Dave Thomas at the September 1978 meeting and entitled "Thoughts on Electronic See and Avoid". User reaction to the logic of this paper was generally favorable, and it served as a springboard for ad hoc technical coordination discussions.

Working Paper by Dave Thomas, GAMA

Ultimate Goal:

To develop equipment and procedures which will enable all equipped aircraft to "see and avoid" all other aircraft under all weather conditions. This goal includes the concepts that:

- Air traffic delays should be caused only by runway or approach path occupancy.
- Air traffic restrictions to flight will be imposed only because of potential actual conflict with other aircraft and not because of procedures internal to the ATC system.
- The system should be able to resolve potential conflicts in operationally acceptable ways.
- System implementation should be evolutionary (i.e., benefits not dependent upon full implementation).
- The ATC system workload (manpower intensity) will be reduced significantly.

Transition Goals:

There is no known technique that will satisfy the "ultimate goal" with its underlying concepts. Therefore, goals that have prospects of being achieved and which lead in the direction of satisfying the "Ultimate Goal" should be considered for the "Transition Period" which probably will require two or more decades. Additional concepts that will govern the "Transition Period" are considered to be:

- Only cooperating airborne equipment will be considered unless some revolutionary breakthroughs in self-contained equipment occurs.
- Equipment carriage will not be mandatory and non-equipped aircraft will be permitted to operate IFR and VFR in all controlled airspace.
- In controlled airspace, ATC must be able to exercise control (or intervene).

- Communications with ATC are required at general aviation airports underlying controlled airspace to provide for efficient control of IFR aircraft departing from those airports.

If these additional concepts are accepted as realistic for the indefinite future, it is clear that:

- The airborne equipment will have to cooperate with the ground ATC system and other equipped aircraft.
- Some type of flight plan will be needed by ATC in advance of departure. As a minimum, destination and desired altitude could be given while taxiing out for takeoff.
- Within controlled airspace conflict resolution could probably be done best by a ground computer. Airborne computation capacity could be limited to that needed for "backup" collision avoidance.

Suggested Development Program:

The above ideas lead to the conclusion that an "Electronic See and Avoid" system that will permit IFR operations within controlled airspace while completely cooperative with and not independent of the ATC ground system is achievable with today's technology, but is not yet economically viable. Therefore, the concept should be retained and pursued as an E&D initiative. In the meantime, the FAA E&D effort should be expended on automating the ground system to reduce controller involvement with continued development of a complementary airborne device which will serve as a backup collision avoidance instrument.

APPENDIX C

Following is a brief explanation of current ground systems in use and their limitations/constraints:

VOR - DME and TACAN

VHF omnidirectional Range (VOR) was developed as a replacement for the Low Frequency Radio Range to provide a bearing from an aircraft to the VOR transmitter. Distance Measuring Equipment (DME) provides the distance from the aircraft to the DME transmitter. The domestic en route airway system is based on a range-bearing navigation aid. TACAN provides both azimuth and distance information and is used primarily by the military.

The VOR transmitters operate in the VHF (112-118 MHz) band and provide omnidirectional azimuthal information. The overall system, including avionics and pilotage, has an accuracy of ± 4.5 degrees (95%). DME operates in the UHF (960-1215 MHz) band and provides distance information with an accuracy of ± 0.5 NM or 3 percent of the slant range (whichever is greater). In most cases the VOR and DME are colocated as a VOR-DME facility. At those locations where both civil and military requirements must be met, a VOR and TACAN are combined as a VORTAC facility. The distance function of the TACAN is the same as the DME.

The Federal Aviation Administration operates approximately 950 VOR-DME/VORTAC stations. An increase of approximately 50 additional stations is planned during the next 5 to 10 years, to meet the requirements in specified areas. The DOD operates 180 VOR and TACAN stations in the U.S. These are available to all users.

Much of the ground-based equipment is between 15 and 30 years old and reaching the end of its useful life. Cost studies have shown that replacing obsolete vacuum tube equipment with solid state equipment will pay for itself in savings on operating and maintenance costs in 4 to 7 years. Based on this, the FAA has planned a replacement program starting in fiscal year 1978 and extending for about 5 years.

Approximately 80 percent of the nearly 190,000 active general aviation aircraft are equipped with at least one VOR. All air carrier aircraft depend on it for bearing information. DME is used to provide distance information for all U.S. air carrier aircraft and for a large number of general aircraft and military aircraft operating in U.S. airspace.

By international agreement through the ICAO, the U.S. is committed to operate VOR-DME until 1985. There are indications that there will be strong pressures to extend this agreement at least through 1995. In any case, it is planned to maintain the system at its present capability through 1995.

Since the VOR-DME system operates at frequencies which are limited to line-of-sight coverage, signals are not receivable in areas where terrain, such as mountains, intervenes between the aircraft and the transmitting sites. However, the system does have an advantage in that it is line of sight rather than noise limited and there is redundant or near-redundant coverage in many areas.

RADIOBEACONS

Radiobeacons are nondirectional radio transmitting stations (NDB). Aircraft equipped with automatic radio direction finders (ADF), receive signals, including identification, to obtain a bearing relative to vehicle heading. Beacons transmit in bands between 200-415 KHz over ranges from 10 NM to 350 NM depending on location, operational objective and power. Bearing accuracy is of the order of ± 3 degrees.

Nondirectional beacons (NDB) are used for transition from en route to airport precision approach facilities and as a nonprecision approach aid at many smaller airports. They also provide the radio aid to navigation for flights where VOR coverage is not available. In Alaska they are an integral part of low altitude airway structure. The beacons also relay transcribed weather broadcasts.

The FAA operates over 300 nondirectional beacons. In addition there are about 500 non-federally operated aeronautical beacons. During the next 10 years, FAA's expenditures for beacons are planned to be limited to an occasional relocation or establishment of NDB for ILS transition, replacement of deteriorated components, and modernization of selected facilities.

LORAN-A

LORAN-A is a pulsed hyperbolic radionavigation system operating in the 1800-200 kHz band. The ground wave range is 600 to 800 NM over seawater and depends upon station power. The sky wave extends the range to 1,500 NM. Predictable accuracy varies from 1 to 2 NM using the ground wave, and 6 to 7 NM when using the sky wave at extended ranges. Most stations providing coverage for the U.S. coastal waters are operated by the U.S. Coast Guard. A few stations in these chains are operated by the government of Canada.

Service provided by the U.S. operated chains in the Aleutian Islands, Gulf of Alaska, Hawaiian Islands and the West Coast will be discontinued July 1, 1979. This is two years after the LORAN-C coverage in those areas is operational. The LORAN-A service in the Caribbean, Gulf of Mexico and the U.S. East Coast chains will be terminated July 1, 1980, after 2 years of concurrent operation with most of the expanded LORAN-C system. The notice to users of the schedule of termination of LORAN-A service was published in the Federal Register July 19, 1974, and was also disseminated in July 1974 with publication of an Annex to the DOT National Plan for Navigation.

LORAN-C

LORAN-C is a pulsed, hyperbolic system operating on 100 khz. Ground wave range is typically 600 to 1,400 NM over seawater. Predictable accuracy of position information is at least 0.25 NM (2-σ rms) in advertised ground wave coverage areas when using automatic receivers of current design. The repeatable accuracy of the system is 60 to 300 feet. With the exception of one station operated by the government of Canada, the stations providing coverage for the U.S. are operated by the Coast Guard.

In 1974, LORAN-C was designated as the U.S. government-provided navigation system for the Coast Confluence Zone. Implementation of the program, authorized at that time, is now underway.

The schedule for LORAN-C implementation to provide total coverage for U.S. contiguous waters and adjacent land areas is as follows:

Gulf of Mexico	Summer 1978
East Coast	
Expanded service	Summer 1978
Complete service	Summer 1979
Great Lakes	Early 1980

The above schedule provides complete LORAN-C operational coverage for the CCZ of the contiguous 48 states and southern Alaska by summer 1979. It also continues to satisfy the previously established DOD requirements.

Since the LORAN-C stations must be land based and they have a useful range of about 1,000 NM, it is not feasible to provide a worldwide system utilizing this technique. This coverage is fixed by the area where an adequate signal-to-noise ratio is available; i.e., the system is noise limited.

OMEGA

Omega is a VLF (10-14 kHz), CW, phase comparison, circular or hyperbolic system. VLF propagation characteristics are such that eight transmitting stations can provide worldwide signal coverage. The design predictable accuracy of the system is 2 to 4 NM and depends on geographic location, station pairs used, propagation corrections, and time of day. The design repeatable accuracy is 1 to 2 NM. Greater accuracies are possible through the use of fixed monitor stations to broadcast local corrections on a real-time, continuous basis, a supplement known as Differential Omega.

The Omega system has been developed and is being implemented by the Department of the Navy, with the assistance of the Coast Guard and with the participation of several partner nations. In addition, other countries are participating in a signal monitoring effort to assist in verifying system accuracy. The purpose of Omega is to provide a worldwide position determination and aid to navigation for civil and military air and marine users.

At present, seven of the eight permanent stations required for worldwide coverage are transmitting. The seven stations are located in Norway, Liberia, North Dakota, Hawaii, La Reunion Island, Argentina and Japan. A temporary station is located in Trinidad. All stations are in normal operation, i.e., they are on air, synchronized, and transmitting at a nominal radiated power of 10 kw at 10.2 kHz. (Trinidad transmits at 1 kw.) Periodic off-air periods and/or low power transmissions are being experienced at some stations which are in the early stages of operation.

The Coast Guard operates the two stations located in the U.S., and contracts the operation of the stations in Liberia and Trinidad, subject to reimbursement by the U.S. Navy. The remaining stations are operated by the partner nations with varying degrees of technical and logistic support from the U.S. Coast Guard.

In addition to the DOD air and marine users, some commercial and private ships and aircraft are using the Omega system. Certain intercontinental air carriers are using Omega to bound the error of their self-contained navigation systems, and as a stand-alone navigation system.

Current information indicates that the existing seven permanent stations provide basic coverage over more than 90 percent of the earth's surface and virtually all of the Northern Hemisphere. It is anticipated that the eighth station will be completed by late 1980. The existing transmitting stations are used for navigation. There is a program going on to measure the coverage and accuracy of the system on a regional basis. This process includes collecting data from fixed monitor receiver sites to correct and update propagation models and tables, and special calibration tests to

confirm propagation parameters affecting coverage and availability. Several air carriers have validated the use of Omega for certain oceanic routes.

The Omega system, while capable of providing worldwide coverage from only eight transmitting sites, is limited in accuracy. While the system design accuracy of 2 to 4 NM is satisfactory for oceanic and high seas navigation, it cannot meet the accuracy required for maritime and helicopter navigation in the CCZ or for aircraft flying over land in some parts of the U.S. airspace.

The primary limitation on Omega system accuracy is due to propagation errors. These can vary from place to place and with the time of day and season in any given place. These errors are reduced by the application of average propagation corrections which are published. These average corrections, however, cannot account precisely for all temporal and spatial error variations. A fixed monitor station, established at a known location, can measure the actual Omega phase differences at its location, observe the difference between them and the predicted values for the location, and thus obtain a local correction for the propagation errors. It has been shown that the instanteous errors measured at a known, fixed location are generally indicative of the errors prevailing at the same time within the general vicinity. These corrections can be broadcast to Omega users in the vicinity. A suitable receiver can apply them automatically as corrections to phase-difference measurements obtained from the basic signals. This augmentation of the basic system is known as differential Omega.

Another characteristic of the Omega system is that the signals from a particular station are unusable in the immediate vicinity of that station. For the two U.S. stations, the questionable area is a circle with a radius of about 600 miles. The phenomenon is not completely understood and full details of the effect in the vicinity of each station will have to await calibration.

INSTRUMENT LANDING SYSTEM

The ILS ground equipment consists of a localizer facility, a glide slope facility, and two or three marker beacons. The localizer provides horizontal guidance about the runway centerline extended coverage from at least 18 NM to touchdown. The localizer's signal emitted from the far end of the runway is adjusted to produce an angular width between 3 degrees and 6 degrees as necessary to provide a linear width of approximately 700 feet at the runway approach threshold. It transmits in the 108-112 MHz band. The glide slope facility provides vertical guidance to an approaching aircraft. The glide path angle is normally 3 degrees above the horizontal. Marker beacons indicate to an approaching aircraft the distance to runway threshold. The glide slope

transmits in 328-335 MHz band, and the beacons transmit at 75MHz. Most ILS provide for Category I landings (Decision Height (DH) 200 feet - Runway Visual Range (RVR) 1,800 feet). Some systems have been improved to provide Category II (DH 100 - RVR 1,200) and Category IIIA (DH 0 - RVR 700) landings.

The FAA presently operates about 528 full ILS facilities, each providing aircraft with vertical and horizontal guidance with respect to a particular airport runway. Ten additional facilities are operated by agencies other than the FAA for a total of some 538 commissioned systems. There will be an increase of about 50 systems by 1982 to meet specific traffic requirements or to provide service at new airports. In addition there are 93 ILS facilities operated by the DOD in the U.S.

ILS avionics equipment is required by FAA regulation to be carried by all U.S. air carrier aircraft. It is extensively used by general aviation aircraft, being required for some IFR approach and landing operations. It is also extensively used by aircraft of other countries, both air carrier and general aviation since it is a recognized ICAO standard.

Terrain considerations are a factor in the installation of ILS. Special account needs to be taken of the signal reflections (multipath) from taxiing aircraft, and other surface traffic. The single approach path provided by an ILS constrains airport capacity and noise control. In regions where many airport runways require ILS, the saturation of current 100 kHz separated radio frequency channels could be the limiting factor on the number of installations.

AREA NAVIGATION

Area Navigation (RNAV) is a method of navigation which through the use of an airborne computer/display system permits aircraft operations on any desired course within the coverage of station-referenced navigation signals or within the limits of self-contained system capability. RNAV in the horizontal plane is also referred to as 2D RNAV and in both the vertical and horizontal planes as 3D RNAV. Addition of time reference to 3D RNAV is described as 4D RNAV.

There has been considerable interest expressed over a period of years in area navigation. This interest on the part of the ATC system user community is based on several points. These include, among others, economic considerations, need for improved or expanded navigational guidance, and, for some, the desire to return navigation to the cockpit rather than the increasing dependence on radar vectors for navigation. From the ATC system pers-

pective, the impact of area navigation on FAA navigation facilities' costs, controller workload and productivity, operations rates and airspace capacity are all beneficial. Safety and implementation costs are of course of major interest to both the system user and the FAA.

Future Systems

NAVSTAR Global Positioning System

NAVSTAR GPS is a system concept under development by the DOD. It is a system to provide positioning primarily for weapons delivery systems, as well as a number of other military missions. It will use satellites to provide worldwide, continuous, real-time all-weather, precision information to users operating equipment in a passive mode. FAA and NASA are investigating such uses, and there may be a wide number of potential applications in the civil sector.

Initially DOD plans to deploy 6 satellites which are to be used to validate the system concept. By the mid-1980s 24 satellites are to be deployed with 8 satellites in each of three 63 degrees inclined plane circular orbits at 11,000 NM altitude. Each satellite will transmit very precise time and the locations of every satellite on 1227 and 1575 MHz. A worldwide monitor network will report to a U.S. based master station which will in turn compute changes to satellite locations and time reporting. User equipment will be of varying degrees of sophistication. The most sophisticated equipment is expected to provide predictable accuracy of 50-100 feet in three dimensions. Less sophisticated equipment is expected to provide less accurate positioning of 300-600 feet at lower cost. The system is so designed that the use of the higher accuracy capability can be restricted to selected users by the system operator. The lower accuracy capability would be available to all users.

If deployed, the degree of its acceptance for civil use will be especially sensitive to the successful design of low cost user equipment. The question of use of NAVSTAR GPS by the civil community internationally raises institutional questions on system management which need further examination.

While present design predictions indicate that NAVSTAR GPS for civil use is not expected to be accurate enough to replace precision landing systems, it may have a technical potential for accurate non-precision (or semi-precision) approaches to any airport in the world.

Microwave Landing System

The Microwave Landing System (MLS) is a joint development of the DOT, the DOD, and the National Aeronautics and Space Administration (NASA) under FAA management. Its purpose is to provide a civil/military, Federal/non-Federal standardized approach and landing system with improved performance and more flexible implementation as compared to the existing landing systems. International standardization of the time reference scanning beam signal format is anticipated.

Approach and landing navigation information is aircraft derived, based on ground transmitted signals. Angle signals, at 5000-5250 MHz, combined with a Precision Distance Measuring Equipment capability, provide data over a wide volume, bounded by $\pm$40 degrees from runway centerline, 2 to 20 degree elevation. The signal format lends itself to a variety of implementation forms ranging from simple and inexpensive to complex. The more complex systems enable landing under zero visibility conditions.

Certain MLS configurations are presently under development. The timing and extent of implementation have not yet been determined. However, widespread use by the U.S. civil and military, Federal and non-Federal aviation is anticipated. After a suitable period of co-existance, MLS is expected to replace the existing Instrument Landing System (ILS).

Penalty or Price

System costs were developed for navigation systems. A most useful document for this purpose with regard to VOR/DME/TACAN is the report of Systems Control (Vt.) Palo Alto, California, FAA Report No. FAA-ASP-78-3 titled "Economic Requirements Analysis of Civil Air Navigation Alternatives", dated April 1978. Since the Systems Control report does not include data on the sunk costs in existing systems, these were determined from reliable sources and added, as noted in the following:

VOR System Costs

Government System Investment

	Year	Number	$ (million)
VOR-DME/VORTAC facilities	1978	960	141*
Second generation VOR/DME/VORTAC systems		960	111
Additional facilities (systems sites)	77-85	50	24

*The value of VOR/DME/VORTAC buildings, sites, access roadways, etc., but not including all the electronic systems. Electronic systems are priced for second generation VOR/DME/TACAN (new solid state-remote monitored).

User Equipment Investment

	Year	Number	$ (million)
DME U.S. air carrier	1977	5,240	65
DME general aviation	1977	33,400	117
VOR U.S. air carrier*	1977	5,240	65
VOR general aviation*	1977	212,920	532

*Including instrumentation.

RADIOBEACON SYSTEM COSTS

Government System Investment

	Year	Number	$ (million)
Aircraft NDB stations	1976	316	32

User Equipment Investment

	Year	Number	$ (million)
ADF U.S. air carrier	1977	5,240	26
ADF general aviation	1977	70,140	91

LORAN-A SYSTEM COSTS

The 39 Coast Guard funded and operated stations existing in 1977 are all of obsolete vacuum tube design and are close to the end of their useful service life. Continued operation would require considerable equipment replacement. No government investment is planned other than the necessary operating and maintenance costs to continue service until the scheduled closed-down dates.

LORAN-C SYSTEM COSTS

Government System Investment

	Year	Number	$ (million)
Transmitter stations	1976	27	
Transmitter stations added	77-80		

User Equipment Investment

	Year	Number	$ (million)
DOD aircraft	1976	900	45
Civil ships and pleasure boats	1976	1,000	4
Civil ships and pleasure boats	1980	77,000	100

OMEGA SYSTEM COSTS

Government System Investment

	Year	Number	$ (million)
U.S. owned & operated stations	1976	2	20
U.S. investment in non-U.S. stations	1980	6	50

User Equipment Investment

	Year	Number	($ (million)
U.S. Maritime	1980	3,000	15
Air carrier aircraft	1980	250	5
General aviation aircraft	1980	200	4
DOD ships	1977	600	16
DOD aircraft	1978	600	16
Foreign Maritime	1978	4,000	20

ILS SYSTEM COSTS

Government Civil System Investment

	Year	Number	$ (million)
Present facilities	1976	538	311
Planned facilities	77-82	50	20

User Equipment Investment

	Year	Number	$ (million)
Air carriers	1976	5,240	45
General aviation	1976	47,000	190

NAVSTAR SYSTEM COSTS

Government System Investment

	Year	Number	$ (million)
Research and development	1990		400
Satellites and control	1990		200
Satellites and control	2000		400

User Equipment Investment

	Year	Number	$ (million)
DOD	1990	27,000	810

MICROWAVE LANDING SYSTEM COSTS

Government System Investment

	Year	Number	$ (million)
Research and development	1980		110
Ground systems	2000	1,250	400

User Equipment Investment

	Year	Number	$ (million)
Carrier aircraft	2000	2,900	190
General Aviation	2000	140,000	750

APPENDIX D

Communications Deficiencies

Definition of Communication Constraint

Communication Defined

For the purposes of our investigations, "communication" is defined as: The art of transferring, exchanging or imparting information clearly from one being to another in forms, formats, symbols or gestures which can be understood, standardized and mutually agreed upon. A communication transaction is only to be considered completed if some mutually understood and agreed upon acknowledgement of reception is fed back from the recipient to the originator. Therefore, effective communication requires all participants to have and use both transmitters and receivers. Transmission of information without operational or technically acknowledged reception is not considered completed communication, nor is reception of transmitted information without acknowledgement considered a completed communication transaction.

Constraint Defined

For the purpose of our discussion, "constraint" is defined as: Compelled, forced or urged, obliged with a power sufficient to produce the desired effect. Synonyms are: restrained, prohibited, prevented from.

Communication Constraints Defined

Hence, the definition of "communication constraints" becomes: Those powers, forces, obligations which prohibit, restrain or prevent transferring, exchanging or imparting information clearly, in a standardized, mutually agreed upon form, format, symbol or gesture which can be understood and freely acknowledged, to maintain the freedom of airspace.

Broadcast Transmission Defined

For the purposes of our considerations, ordinarily termed "mass communication" or one transmission, i.e., "blind broadcast" is considered an attempt to disseminate information irrespective of any confirmation or individual acknowledgement of reception. Information is then considered broadcast but must not be considered communicated. Unless the feedback loop is completed, the fundamental difference in definition between communication and broadcast is often ignored to the detriment of safe, timely and efficient operation of the system.

Explanations and Examples

The generic types of communications constraints in today's ATC System identified by the Group are:

Inability to Communicate Due To:

1. Coverage Gaps: An inability to communicate exists due to inadequacy of communication coverage, which is presently limited by line of sight characteristics of the UHF/VHF frequency spectrum in several areas. This directly constrains the ability to communicate to those transmitters and receivers which are within a line of sight of one another. This results in areas where UHF/VHF coverage does not exist. There is a consistency to these coverage gaps. They tend to exist at low altitude, in low density airspace, and in areas of intervening obstructions. Extensive government sampling, definition and identification records of these communication coverage areas and gaps exist on a specific UHF/VHF frequency basis. Charts of navigation coverage and coverage gaps (Figures 4-20 and 4-22) are available from the FAA, as well as ARTCC VHF communication coverage in ocean airspace under U.S. jurisdiction (Figure 4-17). Similar consolidated charts for all frequencies of VHF communication coverage for the CONUS airspace are not available. Remote communication outlets (RCOs) extend the communication coverage areas considerably. Figures 4-17 through 4-23 comparatively illustrate the relationship between reception altitude and line of sight affects on the ability to communicate. The basic relationship is that an inability for aircraft and ATC to communicate with one another exists at low altitudes (including on the ground) in remote areas, or remote or obstructed airports and as aircraft altitudes increase, reception ranges increase proportionately. Helicopter operators have stated a requirement for communication coverage to the surface and at extended over-water ranges. H.F. provides one method to extend coverage ranges, and is already extensively used for over-water operations. The technical enhancement of single sideband (SSF-HF) have dramatically improved readability, but this frequency spectrum was not originally considered acceptable for many well documented reasons (e.g., costs, weight, interference, propagation). The reasons which lead to selection of the preferred UHF/VHF frequency spectrum continue. Therefore, it is still the consensus that the aforementioned problems associated with H.F. continue to be sufficient to render it an unacceptable alternative for the continental United States airspace.

2. Overlaps: The second characteristic of the UHF/VHF frequency spectrum is the technical limitation of mutual interference due either to overlap or dual simultaneous transmission causing mutual interference. Figures 4-18 and 4-20 through 4-23 typically illustrate the higher altitude

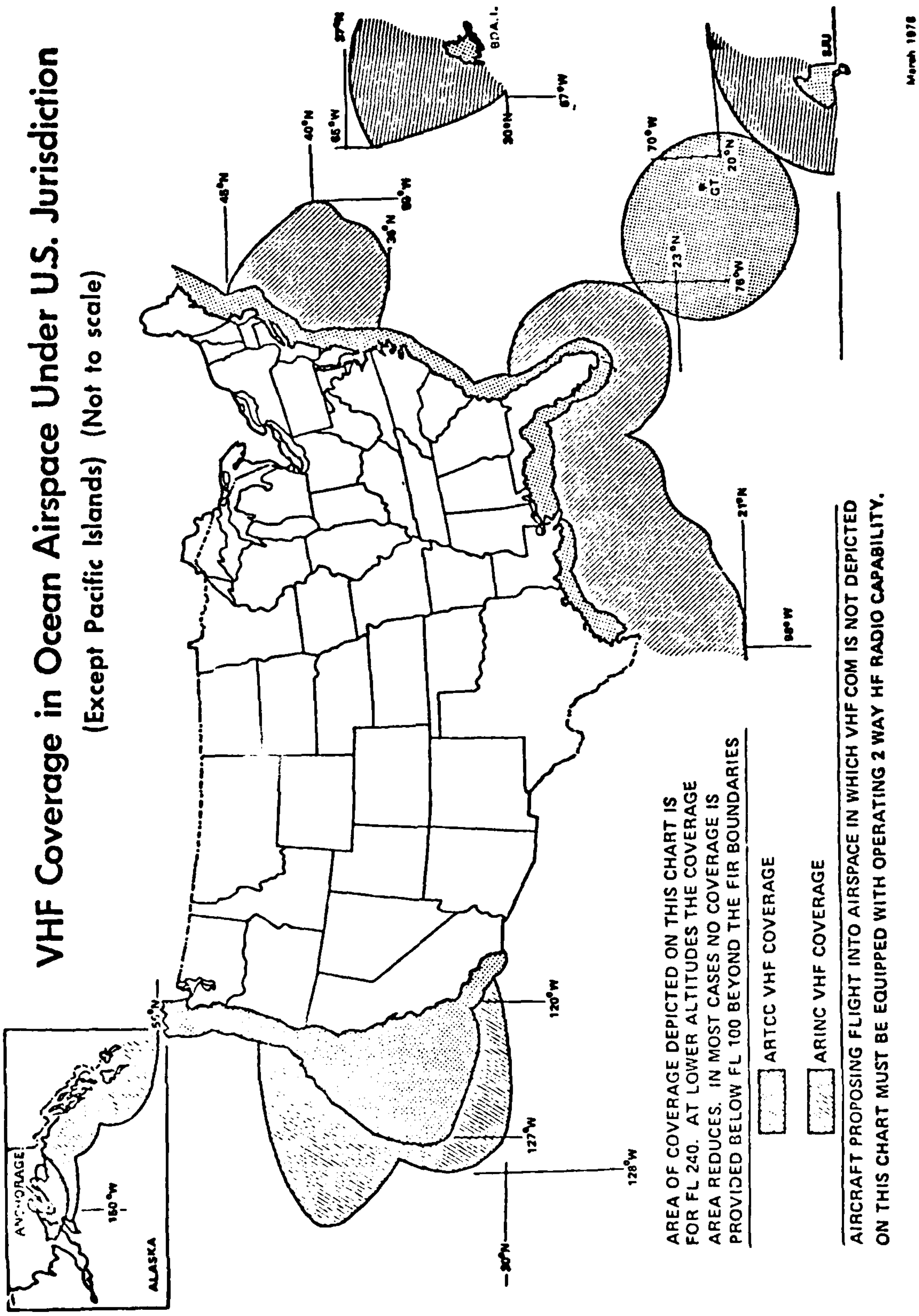

VHF Coverage in Ocean Airspace Under U.S. Jurisdiction
(Except Pacific Islands) (Not to scale)
AREA OF COVERAGE DEPICTED ON THIS CHART IS FOR FL 240. AT LOWER ALTITUDES THE COVERAGE AREA REDUCES. IN MOST CASES NO COVERAGE IS PROVIDED BELOW FL 100 BEYOND THE FIR BOUNDARIES
ARTCC VHF COVERAGE
ARINC VHF COVERAGE
AIRCRAFT PROPOSING FLIGHT INTO AIRSPACE IN WHICH VHF COM IS NOT DEPICTED ON THIS CHART MUST BE EQUIPPED WITH OPERATING 2 WAY HF RADIO CAPABILITY.
ALASKA
150°W
30°N
128°W
127°W
120°W
45°N
40°N
36°N
60°W
65°W
67°W
30°N
BDA.I.
70°W
23°N
78°W
GT
20°N
SJU
21°N
98°W
March 1978

Fig. 4-17

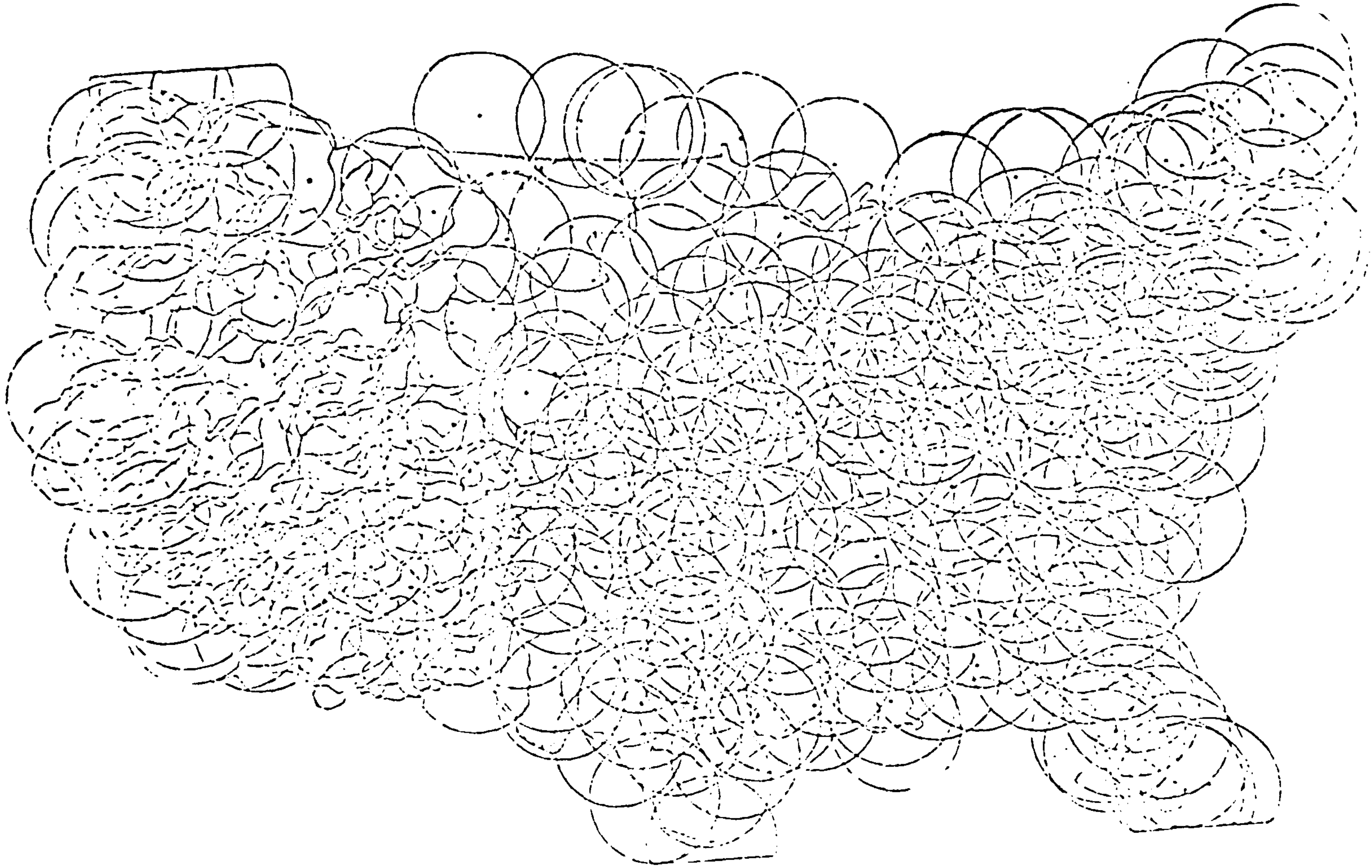


Figure 4-18 High Altitude NAVAID Coverage Patterns
130 nm Radius

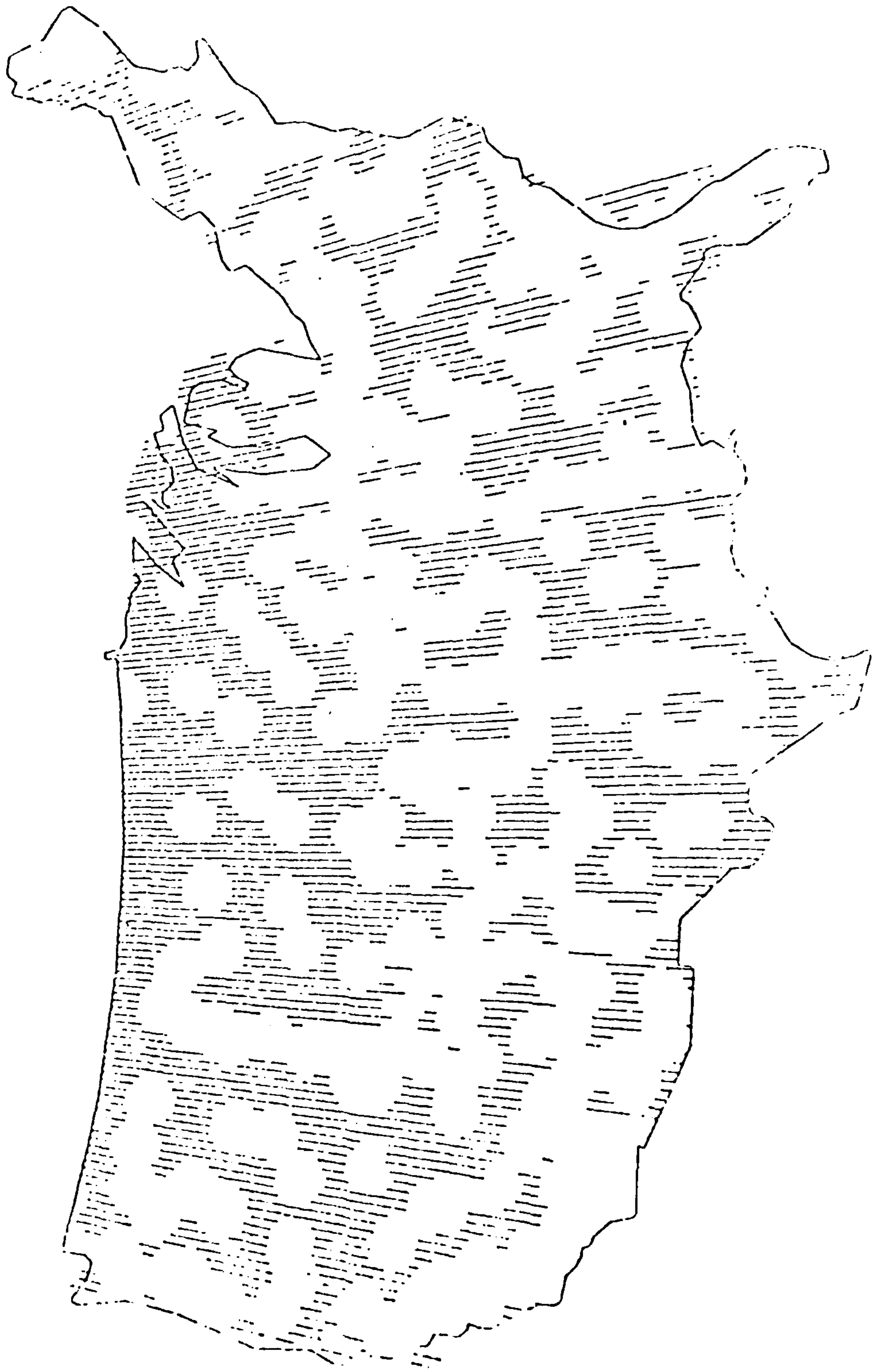


Figure 4-19 Coverage Gaps Based Upon Current High Altitude VORTACs with 50 nm Maximum Coverage Radius (lines represent coverage gaps)

Fig. 4-20 FAA Terminal and Enroute Radars (250 sites)
With 100 nm range rings
(5,000 foot equivalent altitude)

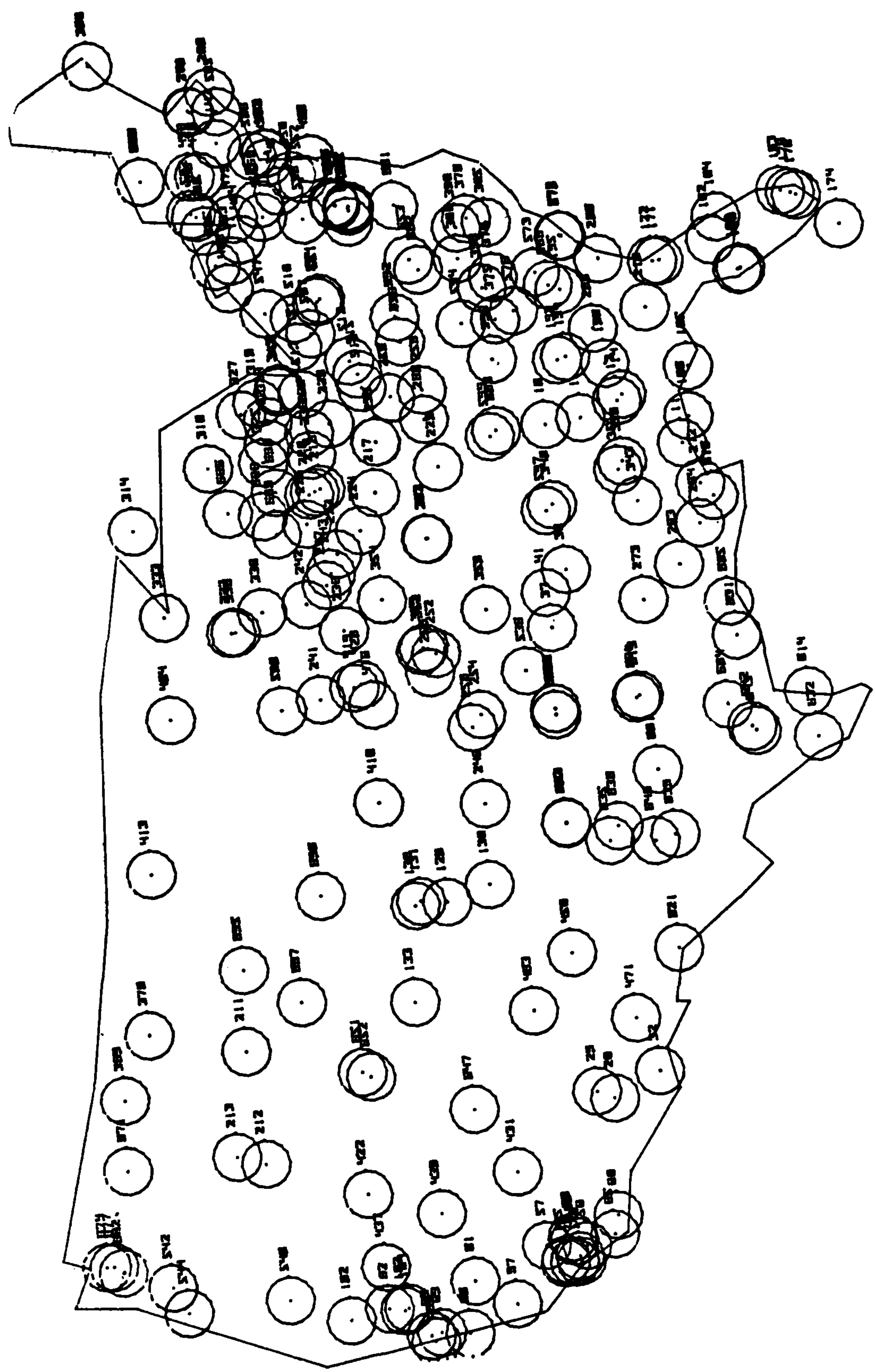


Fig. 4-21 FAA Terminal and Enroute Radars (250 sites)
With 50.nm range rings
(1,250 foot equivalent altitude)

Fig. 4-22 FAA Enroute and 60 ARTS Radars (150 sites)
With 100 nm range rings
(5,000 foot equivalent altitude)

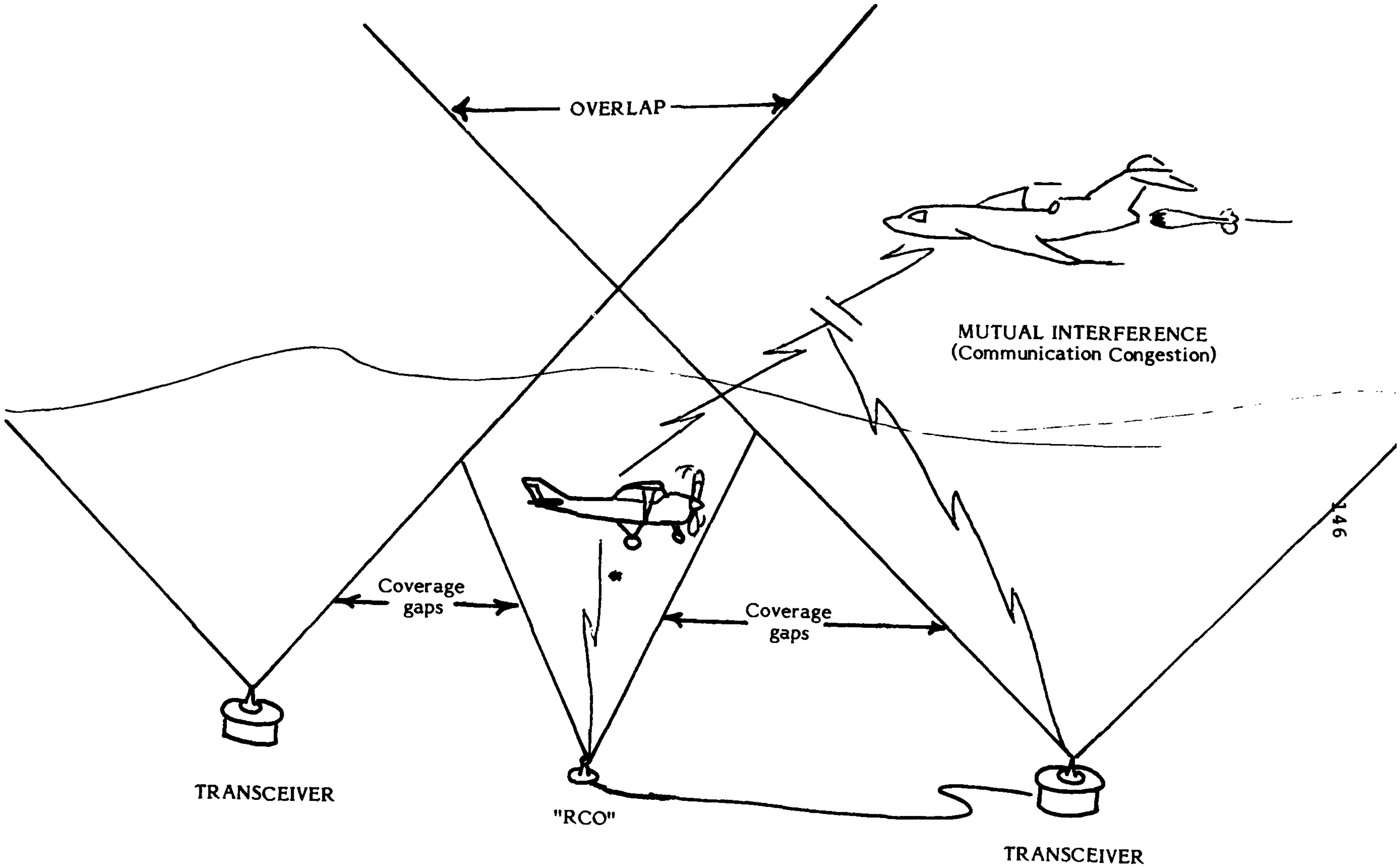

OVERLAP
MUTUAL INTERFERENCE
(Communication Congestion)
Coverage
gaps
Coverage
gaps
TRANSCEIVER
"RCO"
TRANSCEIVER

Figure 4-23

obverse side of the coverage gap problem, the overlap. Flight at higher altitudes results in extended reception ranges. These extended reception ranges compound the interference problem, as the mutual simultaneous reception at extended ranges is difficult to decode and understand. The overlapping areas are kept to a minimum by extensive use of frequency spectrum control and management. Stringent regulations prohibit conflicting high power FM station interferences. There is a continual reassignment of frequencies and power outputs allowable in certain specific geographic areas to attempt to eliminate these conflicting overlaps. FAA has recently developed a theoretical system frequency assignment which shows much promise to improving the "trial and error" techniques of assigning frequencies.[1/]

3. Mutual Interference: Dual simultaneous transmissions cause mutual interference. Additionally, when a mike button is pushed to transmit commonly, the receiver portion of the transceiver is rendered inoperative (or cut out), making any reception impossible. As currently implemented and mechanized, UHF/VHF transmitters interfere with one another during periods when dual simultaneous transmissions are attempted. To date, this problem has been obviated solely by subdivision into closer spaced non-interfering frequency channels within the same spectrum. Channels spaced 200 kHz apart were adequate for the early 1950s, and 100 kHz separation lasted into the 1960s. Now all but very high altitude en route communications are on 50 kHz spaced channels. When these become saturated, channel splitting from 50 kHZ to 25 kHZ is available as a way to overcome the problem.

4. Number of Frequencies Available: The frequency spectrum assigned for VHF air-to-ground communication is from 118.0 mHZ through 136.0 mHZ, and for UHF communication from 225.0 mHZ through 400.0 mHZ. At present 25 kHZ frequency separation is the standard, and reliably provides a non-interference communication link where densities are not excessive on 720 VHF channels.

5. Communication Congestion: Significant communication congestion exists at some 25 high density terminal areas during peak periods on ground control, clearance control, departure control and approach control. Operation rates are sometimes affected by this communication constraint at ATL, BOS, CLE, DEN, DCA, EWR, JFK, LGA, LAS, LAX, MIA, PHL, PIT, ORD and STL. Conversely, very little or no inability to communicate exists in high altitude jet airway en route environment as a function of either congestion or coverage limitations. Communication congestion in the high density terminal area results from use of the radar vector navigation technique, as well as the sheer volume of traffic. The use of predefined conventional SIDs and STARs is diminishing, and existing airborne RNAV

[1/] "FAA Remote Terminal System Frequency Assignment Model", Charles W. Cram, SRDS Progress Report, FAA-RD-78-90, 1978, DOT-FAA.

equipment capability is ignored in the terminal area. User solicited RNAV SIDs and STARs are not being expeditiously implemented. Implementation of 3D RNAV STARs is prohibited, while at the same time 3D profile descents have been implemented. Even the profile descent program has encountered delays due to inadequate definitions. There are no requirements for consistent and adequate flight crew training describing the airspace included and prescribing the flight techniques to be used to adhere to it.

6. Complex Definitions, Regulations, Procedures and Phraseologies:
Another problem area is that of unnecessary radio congestion generated by either ignorance of, or lack of, compliance with prescribed phraseologies and "gabbing". There is a lack of information, knowledge, and understanding of the approved ways to communicate due to complex ATC procedures and regulations defined in court admissible legal jarjon, rather than in plain, understandable English.

"The Airmen's Information Manual" (AIM) and FARs provide long lists of rules, definitions, regulations, examples of phraseologies and recommended ATC procedures, along with a pilot/controller glossary. The number of active airmen not receiving a current subscription to the AIM is enormous, and considered to be indicative of the counterproductive information transfer results of attempting to pass costs on directly to the pilot users. This is a significant "communication" problem in its own right. There is an increasing need to expand dissemination of this useful information on the definitions, prescribed procedures and recommended phraseologies contained in Part 1 to more "active" pilots. Additionally, the AIM lists of restricted weather, FSS, and ARTC center telephone numbers for pilot communication with these facilities should be more widely disseminated. The annual subscription price for this total document has reached the level where even airlines do not provide readily available copies for their flight crews. The committee believed Part 1 of the AIM to be sufficiently important that it would be desirable to partially subsidize the printing of this document to place it in a price category where the vast majority of active pilots would be well able to "afford" a subscription.

Lack of Standardization and Brevity

1. Insufficient training requirements to ensure transfer of communication information:

Lack of standardization has resulted in considerable variations in interpretation. For example, how a profile descent is to be operationally flown. The 37% reduction in communications required and the improvement in fuel economy by 11.6 to 13.1% are broadly considered more than ample

reasons to expand the profile descent procedures to more terminal areas. Yet, there has been no specific training requirement prexcribed to describe the airspace configuration, the procedures to be followed, and recommended techniques to adhere to the procedure. The latitude allowed under the regulation is so broad that one carrier issues a one page bulletin while another puts together a detailed video tape program. Both are FAA approved methods to "communicate" the required information. The general aviation pilot is "hopefully" notified by an advisory circular (which the vast majority never receive).

2. Insufficient motivation for strict compliance:

The majority of training, occurs as "on the job" training by actual experience. Once this is achieved, there is little existing tangible application of the means to enforce pilot or controller compliance unless an incident or accident occurs. The NASA ASRS reports are replete with numerous examples of this fact. One broad brush example constantly being encountered is the radar vector instruction, i.e., "NAL/PAA 45 turn right 060 degree heading", without the controller giving the reason why. The "workload permitting" caveat excuses the controller by delegating to a lower priority, many operationally desirable and safety enhancing communication calls, i.e., "VFR traffic 12 o'clock, 1 mile, heading north", while you are heading south.

High Cost/Expense to Maintain Suitable Air/Ground Communications

1. Airborne equipment costs of air-to-ground communication capability: The costs to equip an aircraft with a 720 channel 25 kHZ VHF transceiver are between \$995 and \$8,000; a transponder costs between \$600 and \$5,6000; an additional \$595 to \$7,400 is required to add Mode C; and air data computer capability is projected at between \$1,600 and \$10,000. General aviation aircraft which are flown IFR generally will have two transceivers and a basic transponder, while a typical air carrier aircraft will have three transceivers, two Mode C altitude encoding transponders and one CADC.

2. VHF/UHF transceivers - ground-based: FAA plans to spend \$115 million over a three year period to commission approximately 50 new VORTACS and to modernize the 958 VORTAC systems by replacing high maintenance vacuum tube stations with new transistorized hardware, but there is neither planning nor funding to retrofit new transceivers into the ATC System. There is a plan to dramatically improve and modernize the communications switching and control system by developing a detailed set of engineering requirements, targeted to be completed by 1979. No completion date for hardware installation is projected, even though current hardware is of WW II vintage. No replacement cost estimates are made by the Group, but the need is considered well established.

The FAA operates some 1,400 remote communication facilities (RCAGs, RCOs, RTRs). The typical RCAG will have 16 receivers and 16 transmittters (4 VHF and 4 UHF plus 100% standby). There are approximately 500 RCAGs in service. These facilities are predominantly equipped with 20 year old vacuum tube equipment and the maintenance workload is high. According to FAA figures, the maintenance for an RCAG can range from $6,000 per year to $46,000 per year depending on the complexity of the facility. In addition, the cost for the leased telephone lines which connect the controller/FSS specialist to the radio are approximately $10 million per year. It is apparent that communications are the most important part of the ATC process and are also costly for the users and the FAA. Efforts which could improve efficiency and performance and/or reduce costs are probably well worthwhile.

3. Data Interchange Network: A National Airspace Data Interchange Network (NADIN) of digital message switching is being designed to replace a number of the independent WW II vintage low speed teletype networks and switches. It is intended to integrate the present Aeronautical Fixed Telecommunications Network (AFTN) and the Service B System and selected Service A weather data and the NAS NET into a single aeronautical user message network. Overloads presently frequently occur, particularly during severe weather, and the modernization and consolidation of the FAA's discrete data transfer networks into a single common user network should provide an integrated ground to ground digital communications network by the projected 1981 deadline. The costs of this ground communication network improvement are not known by the Group, but the need is considered well established.

Penalty or Price of Communication Constraints

There are significant penalities due to these communication deficiencies, and equally significant benefits to be realized by the improvements. Most of the penalities are usually associated with delays, but other, more significant penalties occur.

Inadequate Coverage

1. Delays due to procedural separation during IFR approaches.
2. Delays due to procedural separation during IFR departures.
3. Delays in getting weather and other FAA information and in filing flight plans.

Communication Congestion

1. Congestion on approach control frequency can limit arrival capacity.
2. Congestion on clearance delivery, ground control and departure control frequencies can cause unnecessary and costly delays.
3. Access to airspace is desired.

Additionally, safety can be greatly impacted by these communication constraints. All the above-mentioned communications constraints impact the freedom of airspace in the following ways:

Pilots often find that the flight plan they filed is lost when they attempt to obtain a clearance to proceed IFR. Frequently, the communication gets "lost in the system", even when prefiled, initialed, and in some cases when "center stored". This results in an inability to expeditiously enter the ATC system, and frequently adds to the existing communication channel congestion. Time delays in obtaining a clearance are often encountered. Unique and special treatment priorities are sometimes established on a basis other than "first-come, first-served". Safety is derogated since pertinent weather, navigation or communication facility outages information (radar vector headings or other critical traffic and wake vortex advisories) or useful information often cannot be communicated in a timely manner. Frequently, access to the IFR ATC NAS is denied. Quotas are sometimes established as a result of the limited ability of one man (an arrival sector controller) to simultaneously communicate with and navigate seven to ten aircraft and capacity is limited at some eight to ten high density terminal areas. Deregulation and increased operations are expected to additionally impact the number of capacity limited airports.

APPENDIX E

Statement by

Glen A. Gilbert
Aviation Consultant

Before the

House Subcommittee on Transportation, Aviation and Weather
September 27, 1978

My name is Glen A. Gilbert, an independent Aviation Consultant for over twenty years with more than forty years of experience in aviation, covering U. S. Government service, United Nations service and private industry activities. A biographical summary with further details is attached.

I appreciate the opportunity of appearing before this distinguished Sub-Committee and participating in its annual review of the FAA E&D programs. Before proceeding with my testimony, with your permission, Mr. Chairman, I would like the record to note that my testimony of today incorporates by reference my statement given before this Subcommittee on May 7, 1976, on "The Future of Aviation". I consider that the elements contained in that statement are still valid.

First of all, I would like to commend the FAA for its program, initiated earlier this year, to have industry groups provide recommendations on FAA E&D initiatives. I believe that the results will provide useful guidelines for future FAA E&D programs. The FAA has discussed this program previously with this Subcommittee, so there is no need for my going into this matter further.

I also would like to commend the FAA for its new helicopter development program just now getting underway. As a consultant to the Helicopter Association of America, which represents a broad segment of the helicopter industry, I can safely say that the helicopter industry strongly supports this program and, in fact, played an important role in encouraging the FAA to take this initiative. This activity thus forms a new part of the overall FAA E&D program. Again, the FAA has apprised this Subcommittee of this program, so there is no need for me to go into further detail in this statement. I would like to add, however, that the helicopter industry definitely supports the FAA's plans for five year funding of this program, and I urge that the Congress provide for such funding opportunely.

Going now to some of the specifics of the FAA's current E&D programs, I should like to express some views in the area of Air Traffic Control. Area navigation probably is the single most effective tool now at hand to increase ATC system capacity and reduce controller work load. A 1972 FAA/industry task force recommended a plan that called for two steps of RNAV implementation in 1977 and 1982 leading to RNAV as <u>the</u> nav system replacing the high and low altitude airways.

Nothing significant was done to execute this plan, however. On January 7, 1977, a more comprehensive RNAV implementation program was signed by

the FAA administrator, who issued a statement saying "The FAA recognizes the advantages that RNAV offers to both the ATC system user and operator and will pursue a two-part program leading to the ultimate objective of an RNAV based airspace structure". In the nearly two years since this statement was issued, very little has been done by the FAA to implement its provisions.

It should be emphasized that VOR/DME sensors are not the only source of RNAV capability. Now under general consideration by the FAA as other sensors are Loran C and VLF/Omega for all classes of aircraft, including helicopters. The DOD Navstar/GPS offers very promising prospects as another RNAV sensor which should be fully operational by the mid-1980's. The FAA is now initiating some feasibility studies along these lines which are very interesting and useful. I will express some further personal views on Navstar/GPS later on in this statement.

Much has been said with regard to the general subject of "distributed management" in the ATC system. It is important to avoid semantics that may tend to obscure or confuse its inherent meaning. Consequently, simple definitions of "distributed" and "centralized" are useful reference terms. Webster says that "distribute" means to "divide among several or many , to deal, allot". The same source defines "centralize" to mean "to bring to a central point, to bring into one system, or under one control".

In applying these definitions to ATC system engineering, an extreme in either direction certainly would not be desirable. As a comparison, a 100% centralized management system of our automobile traffic, in which every individual automobile would be directed (hand carried) by a policeman would be completely unmanageable. Yet, this is pretty much how our ATC system is designed today. On the other hand, 100% distributed management would not be feasible, any more than it would be in our automobile traffic system by letting each motorist do what he felt like doing without regard to such constraints as stop-go lights, speed limits (maximum and minimum) and one-way traffic.

Thus, it is considered that the question to be addressed should be the extent to which air traffic control functions (management/responsibility) could be distributed most beneficially, as between the controller and the pilot. Putting it another way, perhaps the clearest description of the subject area to be dealt with in this context is optimization of ATC aircraft separation responsibility and air-ground work load distribution. A fundamental objective should be to strive to increase system capacity under IFR as closely as possible to VFR capacity.

This approach involves greater delegation to the pilot for separation and spacing functions and better airspace/airport utilization by means of airborne equipment that will provide new pilot-controller tools in the ATC system. The controller thus becomes primarily concerned with data collection and flow control, assisted by ground computer complexes. A mix of automation and the human element is conbined with suitable interfaces.

The new pilot-controller tools would include widespread implementation by the FAA and system users of such developments as airborne area navigation equipment, data link air-ground-air and air-air communications, airborne displays of traffic control information and instructions in a form that could become a multifunction display (MFD), proximity measurement (station keeping) and collision warning instrumentation, and airspace allocation and structuring to facilitate pilot capability to directly participate in the segregation of aircraft with different performance characteristics and mission requirements.

It is only through this type of philosophical approach in development trends that I can forsee an ATC system that will be capable of having the capacity and flexibility to handle efficiently our constantly expanding total air transportation needs, for both fixed-wing and helicopter aircraft with the cost of system admission for all being commensurate with the level of individual service desired.

Before going into my thoughts on certain aspects of Navstar/GPS, I would like to express some comments, as requested by the Subcommittee, on the DOT/FAA report "Economic Requirements Analysis of Civil Air Navigation Alternatives".

Basically, I think that this report contains a very useful model with which to exercise different combinations of inputs relevant to various navigation parameters. An important consideration in exercising the model per the report was estimated cost values of different navigation system combinations or alternatives. In the case of Navstar/GPS cost values, the contractor used the best estimates available to him at the time, according to the report.

However, I want to emphasize that production quantity, as we all know, is an important price determinant. In this respect, I, together with several colleagues, have just completed an extensive report for the Aerospace Group for Advanced Research and Development (AGARD) of NATO on "Civil Applications of Navstar/GPS". This report covers land, sea and air applications. On this basis, we came up with a potential total civil user population well into the millions. This kind of production quantity of Navstar/GPS receiving equipment would put an entirely new dimension on cost estimates. As an example of production impact on cost, consider what a pocket calculator cost 10 years ago and what it costs today!

I therefore recommend that the FAA re-exercise its economic navigation model using Navstar/GPS equipment cost estimates based on a land/sea/air total user population. I am sure that the results will be quite different and very favorable to Navstar/GPS.

I will conclude my statement with a brief dissertation on the key question of availability of the DOD Navstar/GPS for civil applications. I want to emphasize that these views are entirely my own.

DOD is deploying Navstar/GPS as a positioning system in support of weapons delivery. The inherent value of the most accurate information - that is, in the order of 10 meters in three dimensions - is adequate for many military systems. Therefore DOD has stated that the military may deny the availability of the more precise signal under certain conditions. The signal would

be otherwise available to the civil sector. A "coarse" signal with accuracy in the order of 70-100 meters in three dimensions, also may be degraded or even denied by the DOD.

On the surface this policy appears to be forthright, specific, and unambigous making civil application highly questionable. However, there are a number of reasons to examine that policy in greater light as it pertains to a more or less guaranteed availability of the precise accuracy signal for civil use. First, in the interest of national security the military should have the capability to deny the use of such precise information to an enemy. In fact, under Executive Order 11161 the Department of Defense will assume control of the National Airspace System and the nation's navigation aids under certain emergency or hostile conditions. Therefore, DOD can in rality deny any navigation aid under the control and operation of the United States. Therefore, irrespective of a stated explicit policy for some portion of a specific system, under essentially the same conditions the military already may deny <u>any</u> information to civil users.

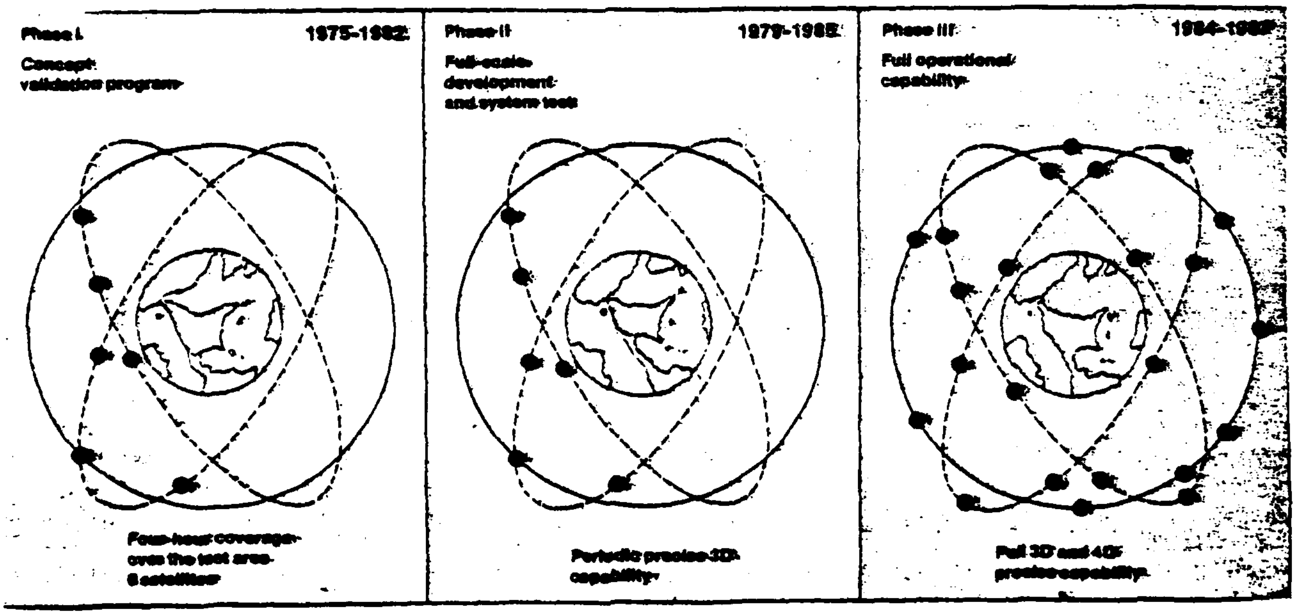
Policy is one matter, but what are the practicalities of availability and denial to civil users? There are at least two reasons why the coarse and precise signals will be available to civil users under normal, peace time conditions. First, it is likely that the Department of Defense will seek to involve the total national sector to improve the economy of the system to DOD. Second, as with the Navy Navigation Satellite System, any civil use of the system will stimulate an accumulating demand. The relative, good attributes of Navstar/GPS - precision, non-saturability and economy - will become apparent to the civil and public sectors to include Congress so that there will be an ultimate requirement that DOD share the system in the fullest sense. It seems reasonable that sooner or later Navstar/GPS must become a national system or another satellite system would have to be deployed. The latter would undoubtedly be a relatively costly alternative.

What about under conditions of hostilities? DOD must be able and willing to carry out denial to make the threat of denial credible to an enemy. They should not be constrained to keep the signal on, and indeed they are not required to keep any navigational aid on when control of the nation's navigational aids is transferred to the Department of Defense. At the same time DOD must make the system available to its own forces, cooperating allied forces, and supporting reserve forces, and such civil carriers as the Contract Reserve Air Force. It does not seem practical that the navigation signal could be made available to such a wide number of friendly forces and denied to others except at great cost. Therefore, the Department can maintain a threat and capability to deny the system, provide the signal under almost any circumstances, and weigh national consequences at times when it believes it might be wise to deny the signal. Provided the civil sector agencies of the Federal Government join in (as they should) to advocate the system's use, there would obviously be only the direst circumstances when the precise signal (and only the precise signal) would be denied.

Even so, how would such denial be manifested? Individual VORTACs may be cut off independently (although it is not clear how such would be carried

out practically). LORAN and OMEGA stations may be shut down easier, but with wider implications. TRANSIT satellites' transmissions presumably can be interrupted, but again the implications would be large for the possible returns. Discontinuance or denial of Navstar/GPS precision signals would also have wide implications. Presumably the Department of Defense could want to deny the precise information in specific geographical areas although a large volume would necessarily be affected. It is conceivable, for example, that precise information could be denied Europe, Africa, or Asia without denying the signal to the United States, by transmissions at selective times.

In summary, the availability for civil use of the Navstar/GPS signal, and more particularly the precise accuracy signal, is mostly a political issue as opposed to a technical one. If the Federal Government as a whole were willing to designate Navstar/GPS as a national resource, I think that potential civil applications could then be examined in a dispassionate and objective manner. I understand that the FAA has initiated some inquiries to this effect with the DOD. However, I think that this matter is so vital that it requires suitable action by the Congress and/or Executive Order treatment. Perhaps this Subcommittee and its parent Committee on Science and Technology (including Congress in general) may wish to consider taking a leading role to initiate action along these lines, in cooperation with the Executive Branch. I consider resolution of the question of reliable, accurate Navstar/GPS availability for civil users to be crucial as to where we go in civil sector implementation of this promising navigation/communication/surveillance system.



DOD Navstar/GPS Implementation Schedule

Statement by Glen A. Gilbert
Helicopter Association of America

Before the

FAA/NASA GPS Seminar
October 17, 1978

POTENTIAL GPS APPLICATIONS FOR HELICOPTERS

It has been my pleasure to complete within the last two months a comprehensive presentation on civil applications (land, sea, air) of the DOD's Navstar Global Positioning System (GPS) for AGARD NATO.

In this presentation today I will comment on a limited but important segment of the potential general aviation GPS users, i.e. helicopters.

Today, there are something over 6,000 helicopters in the U.S. civil aircraft fleet. Of this number over 55% currently are engaged in commercial operation, about 30% in business/corporate activities and 15% in government-type work. Civil helicopter production now has a 12% annual growth rate. By the mid 1980's we expect about 10,000 helicopters of which some 5,000 will be IFR capable.

VFR/IFR

A basic criterion related to helicopter operational environments is "weather", e.g. VFR or IFR. Because of the unique capabilities of the helicopter to reduce speed and hover when necessary, it is possible to fly in weather conditions below normal VFR limits. This type of operation, known as helicopter special VFR (HSVFR) can be accomplished as long as the pilot can maintain visual contact with the surface and identify position, desired flight path, and reporting points. In such circumstances navigation requirements are minimized. HSVFR, as well as basic VFR, is used by operators to a considerable extent, and its continued authorization by the FAA and ATC is an important helicopter operational requirement.

The question has been raised many times "Why go IFR?". The helicopter operators say "What does it buy me?", "What are the advantages?". Public officials - operators of airports, airways and the air traffic control system - ask "Why should we change or modify the present fixed-wing (CTOL) method

of handling air traffic without a demonstrated need shown by helicopter users?".

Improving Safety

A survey of U.S. helicopter accidents involving fatalities and/or substantial or total destruction of the helicopter made recently by the author in cooperation with the National Transportation Safety Board, the Helicopter Association of America, and Bell Helicopter Textron, indicates that a significant number of these accidents were caused by operational factors such as:

- Attempting to continue under VFR into adverse (IFR) weather conditions.
- Initiating VFR flight in the face of existing IFR weather conditions.
- Flying at night (no horizon).
- Spatial disorientation.
- Whiteout (terrain snow covered).

All of the accidents resulting from the above basic operational situations ended in a collision (controlled or uncontrolled) with the surface or with man made obstructions. None of the helicopters were IFR equipped and none of the pilots were IFR rated. It is logical to presume that had these operations been conducted in accordance with IFR, the related accidents would not have occurred.

Increasing Vehicle Productivity

With the significant investments involved in a modern helicopter, it is essential that the vehicle be operated at the highest possible level of productivity. The scheduled airlines and most business aircraft operators long ago learned that, for economic reasons, they had to have a high productivity level for their fixed wing aircraft, and that such productivity could only be achieved by having virtually all-weather (IFR) capability. The same situation applies today to helicopters, whether they are flying off-shore, in remote areas, or whether they are being used for business/executive/commuter/police/ or rescue purposes.

Expanding Air Service

Because of the small landing/takeoff area needed by a helicopter, the

potential for developing helicopter service virtually is unlimited. Where surface locations are not available, heliports may be elevated, such as on rooftops, over railwoad yards, above warehouse areas and so on, as well, of course, as on off-shore platforms. However to provide really reliable helicopter service to the many potentially desired landing/takeoff areas, all-weather (IFR) capability is essential.

Helicopter Operational Categories

In addition to the two basic weather criteria, helicopter operations may be categorized also by area or type of operation. Off-shore operations come to most people's minds first because this activity is quite widely known. Operational requirements for off-shore operators may involve special controlled airspace extending out to sea several hundred miles and down to the surface in some instances, requiring adequate navigation coverage.

The remote area category generally applies to such locales as Alaska where there is a great dearth of facilities and particularly difficult flying conditions. IFR operational capability is considered a must for virtually all flights, not only due to adverse weather, but also to "whiteouts" causing spatial disorientation and the extended amount of night flying required.

Operations in the Continental United States constitute the third category of helicopter areas of application. In the CONUS some NAS requirements exist which are not particularly significant in off-shore and remote area operations. Interface with the ATC system is a principal consideration in this respect.

In other words, the trend is now underway to move helicopter operations more and more into the ATC environment as a result of increasing IFR, virtually all-weather operational requirements. In this respect, one of the fastest growing segments of the helicopter fleet is that involved in business and executive operations. From an operational requirements point of view, helicopters in this category will need to at least match the weather minimums of the scheduled airlines as they will be providing, in many instances, a complementary or connecting type service.

Navigation Goals

What are the implications of the foregoing requirements on helicopter navigation goals?

A fundamental goal is to have a high accuracy navigation system with global coverage, capable of providing area navigation (RNAV) without the need for point reference navigation aids. Signal coverage should be down to the surface without the constraints of line-of-sight (radio horizon) limitations.

The navigation system should be capable of providing narrow, discrete helicopter routings to facilitate segregation of helicopters and conventional takeoff and landing (CTOL) aircraft. Similarly needed are discrete instrument approach and missed approach procedures to heliports, helipads at CTOL airports and points-in-space, requiring a minimum of airspace.

Thus, it should be possible to operate helicopters without interference to or from airlines and other conventional aircraft, in many cases sharing the same landing areas, but not the same runway. The potential of helicopters cannot be achieved if they are to be handled in the ATC system as fixed-wing, conventional takeoff and landing aircraft, particularly in high traffic density areas.

For optimum IFR helicopter operational flexibility, and particularly in the application of discrete IFR helicopter routings and approaches, an RNAV system of some sort is needed, as mentioned previously. This system can be based today on such sensors as VOR/DME, TACAN, Omega and Loran C. Of great promise for the future for all-weather helicopter RNAV navigation is the DOD's Navstar GPS. More on this subject later on in this statement.

The Case for an Improved RNAV System

The increasing use of civil IFR helicopter operations has focused sharp attention on the deficiencies of the present VOR/DME navigation system. These basically are the lack of precision navigation guidance, line-of-sight limitations for low altitude flight, and unavailability of stations off-shore and in remote areas. Other types of navigation available today similarly have various types of limitations for optimum helicopter use.

Furthermore, the present national navigation system permits "precision" instrument approaches only where an ILS (future MLS) or PAR (precision approach radar) system is installed. There are about 13,000 aircraft landing facilities in the United States and its possessions, including nearly 3,500 heliports, of which about 300 are elevated, yet precision instrument approach facilities are available for less than 500 conventional airports, and none for heliports. VOR/DME RNAV

instrument approaches can be conducted only when within 25 miles of a VORTAC and then only with relatively high minimums.

The present nav system limitations become even more pronounced when considering the growing need for precision or "semi-precision" approaches to virtually an infinite number of landing/takeoff areas for IFR-capable helicopters and other VTOL's now being developed. For example, approaches to city-center heliports, to discrete helipads at conventional airports, to constantly changing locations for servicing of pipelines, to thousands of off-shore oil platforms, to unpredictable locations for emergency rescue, and so on.

Navigation System Requirements

The ideal halicopter navigation and positioning concept would be one which would have all of the following capabilities in an integrated system:

- Highly accurate airborne area navigation (RNAV) capability so that airway/route widths could be no greater than 0.5 nm, either side of centerline.
- Sufficiently accurate approach and landing guidance by the airborne RNAV system so that minimums approaching "precision" instrument approaches could be achieved to any pilot-selected point on the surface, or in space, without the need necessarily to have an electronic landing aid at that location.
- Ability to function without line-of-sight (radio horizon) limitations.
- Vertical velocity measurement accuracy in the order of 0.1 feet/second; horizontal velocity measurement accuracy in the order of 0.1 knot.
- Three-dimensional (lateral, longitudinal, vertical) 3-D navigational guidance sufficiently accurate to supplement or supplant barometric altimetry.
- Four-dimensional (4-D) Guidance adding time referenced navigational capability to 3-D guidance with extremely high time positioning accuracy.
- Imperviousness to atmospheric conditions for noninterrupted operations.
- Non-saturable capacity.
- Service availability to all classes of airspace users on a worldwide basis.
- System outputs capable of inputting advanced multi-function cockpit displays, including display of ravigational and traffic situation information.
- Data link capability to transmit x-y-z coordinates for automatic position reporting and air-to-air separation assurance.

- Be cost-effective based on life cycle cost analyses, with the system design such that it can have various levels of sophistication and thus will be affordable to all classes of airspace users.

Benefits

Assuming the successful implementation of a navigation and positioning system meeting the requirements outlined above, numerous benefits for helicopters can be visualized along the following broad lines:

- More efficient use of the airspace.
- More efficient use of CTOL and STOL airports.
- Greater flexibility in the availability of landing/takeoff areas.
- Increased safety.
- Increased efficiency in the air traffic control system.
- Savings to the government (i. e. to the Federal Aviation Administration in the context of this statement) as a result of eventually decommissioning facilities now in use (e. g. VOR/DME) and reducing the need for new local landing facilities (e. g. MLS/ILS).
- Savings to the airspace users as a result of eliminating the need for certain airborne avionics equipment (e. g. VOR/DME; ADF; RMI; perhaps ILS/MLS for some operations).

Cost/Benefits Analysis

Four broad assumptions are made in the light of the foregoing dissertation:

- That the desired navigation and positioning requirements can be met most effectively by a satellite based system.

- That the satellite based system most likely to achieve these requirements in a realistic time frame is the DOD Navstar Global Positioning System.

- That the DOD under any circumstances would not deny use of nor degrade precision ("P" signal) accuracy of the GPS for civil aviation.

- That charges would not be levied against civil aviation for use of the GPS.

Thus, in order to determine the degree to which such a system would be used from the standpoint of civil aviation, a cost/benefits analysis would appear to be needed as the first step. As a prior condition for such an analysis, however, a life cycle costing (LCC) analysis of the GPS would be essential. The civil

aviation LCC analysis would use as a base line the DODLCC for military use.

Once this phase has been completed, an analytical study should be initiated covering relevant aspects of civil aviation use of GPS including:

- Development of GPS implementation and integration program plans.
- Technical and operational system analysis.
- Economic Benefit and Payoff analysis.
- Specification of minimum acceptable GPS airborne equipment characteristics.
- Generation of a low cost GPS hardware specification.
- Development of detailed ground system phase out plan acceptable to government and industry.
- Test plan development.
- Performance of test plan.
- Analysis of test results.
- Test evaluation and conclusions.

The FAA has indicated that it already has initiated some actions along the foregoing lines, which certainly are encouraging steps.

Conclusions

- Helicopters have become, and are becoming more and more, a vital element in the nation's total air transportation system.

- Due to the unique characteristics of helicopters (and future VTOL's) discrete routes and approach procedures are needed in many instances to provide segregation of this type of air traffic from CTOL traffic.

- Instrument approach capability is needed to serve an infinite number of locations (both on the surface and elevated) without the need to necessarily have an electronic aid at each such location.

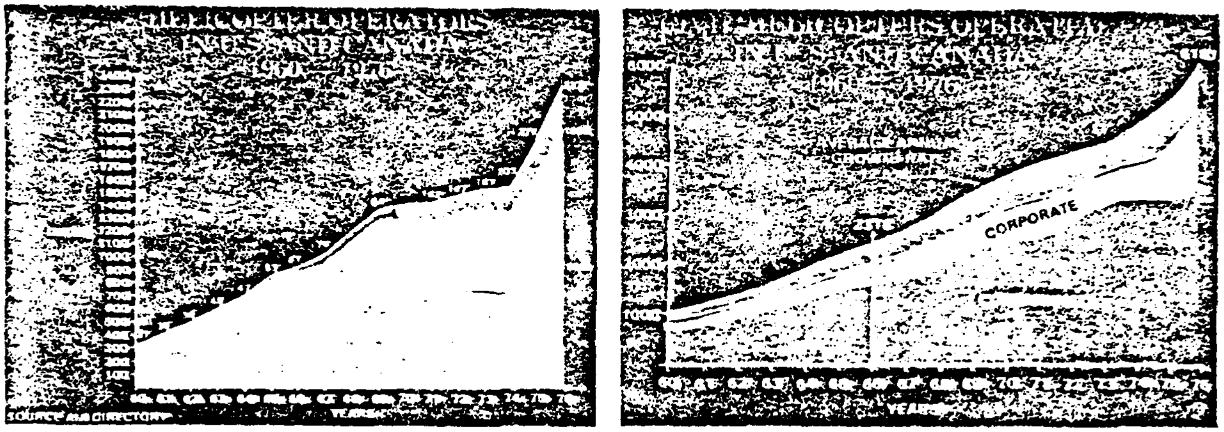
- Area navigation (RNAV) is a <u>must</u> for successful helicopter IFR operations.

- Current RNAV systems do not fully meet helicopter navigation goals.

- GPS appears to be the most logical candidate for a fully satisfactory helicopter RNAV system.

- If certain problems of GPS implementation, as mentioned previously, can be worked out, which hopefully will be the case, GPS implementation by helicopters may very well lead GPS implementation by other segments of civil aviation.

ILLUSTRATIONS

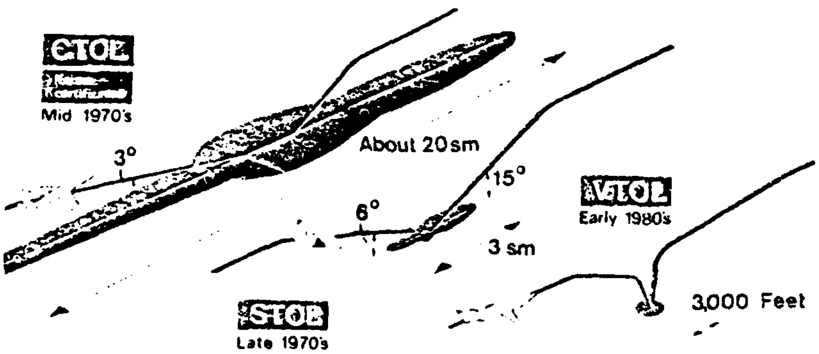


The developing helicopter era.

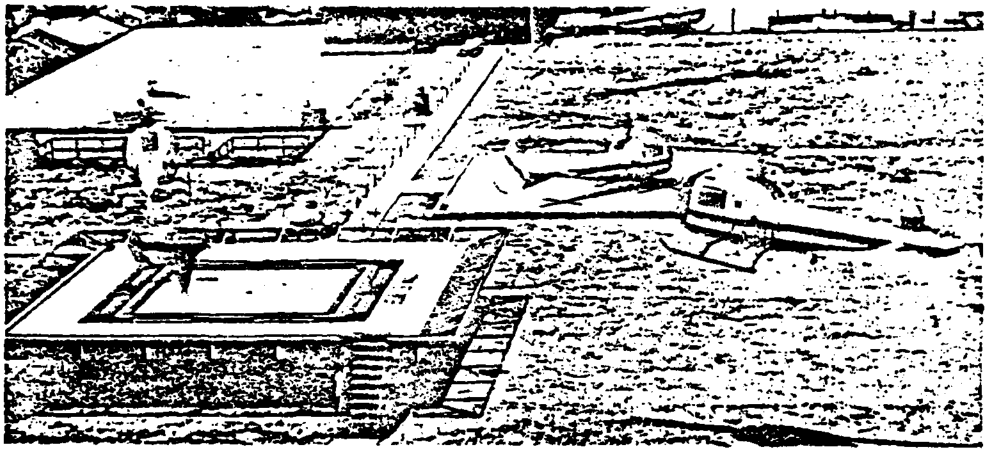
Manufacturer	Type	Passenger capacity	Cruise speed	Range	IFR certification
Aérospatiale	SA 330G	19	150 kn	400 nmi	Completed
	SA 341	4	130 kn	400 nmi	Completed
	SA 360	13	150 kn	400 nmi	Under way
	SA 365	13	150 kn	450 nmi	1977–1978
Bell	206B	4	125 kn	395 nmi	Completed
	206L	6	125 kn	385 nmi	Completed
	212	13	110 kn	290 nmi	Completed
	222	7	160 kn	400 nmi	1977
	301	12	300 kn	500 nmi	Early-1980s
Boeing Vertol	BO 105C	4	125 kn	325 nmi	Late-1976
	107 (CH 46)	25	140 kn	500 nmi	Completed
	179 (UTTAS)	20	155 kn	475 nmi	1980 (civil)
	234 (CH-47)	44	165 kn	290 nmi	Completed (military only)
	HLH (XCH-62)	32 tonnes	135 kn	300 nmi	Design status
Sikorsky	S 58T	16	125 kn	280 nmi	Completed
	S-61L/N	30	130 kn	310 nmi	Completed
	S-65C	44	160 kn	500 nmi	Late-1970s
	S-76	13	155 kn	470 nmi	1978
	S 78 (UTTAS)	20 29	160 kn	400 nmi	1980 (civil)
	Advanced ABC	90	350 kn	350 nmi	1980s

Notes Some of the above models are or will be certificated for single pilot IFR operations others with two pilots. For aircraft still on the drawing board both the technical data and IFR certification dates are estimated

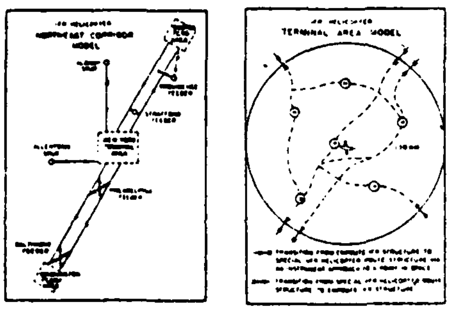
Helicopter IFR certification status of four major manufacturers.



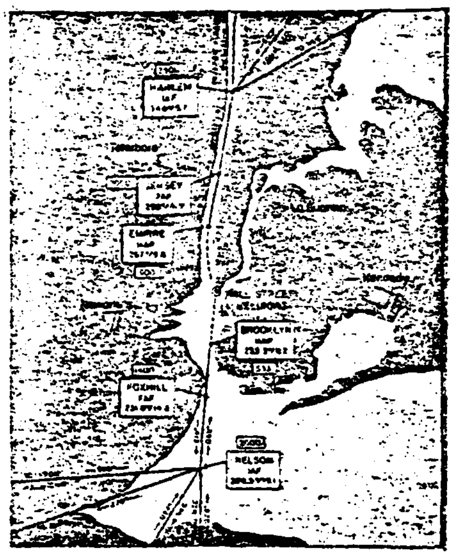
Comparative noise footprints - CTOL, STOL, VTOL (helicopter) at 90 EPNDB.



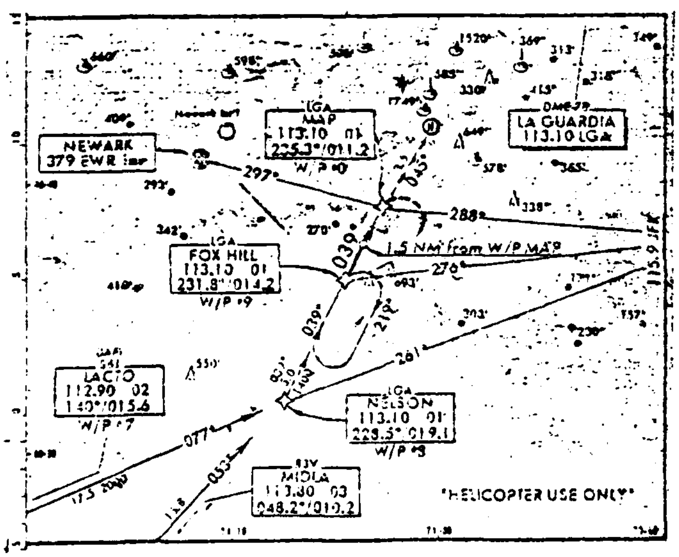
Rooftops can serve as heliports without requiring extensive new construction.



Northeast Corridor IFR route structure model.



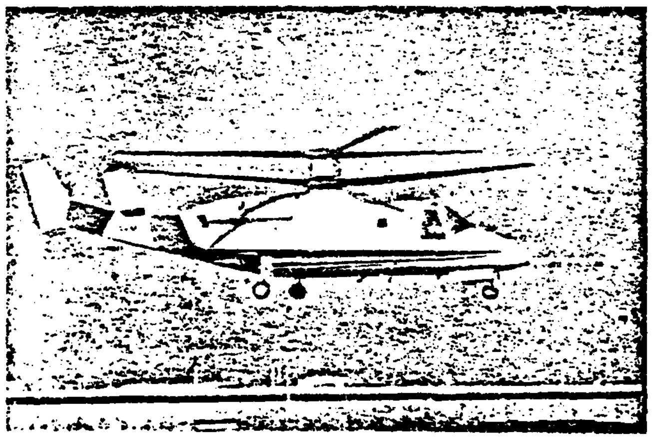
Discrete RNAV IFR helicopter routing in New York area.

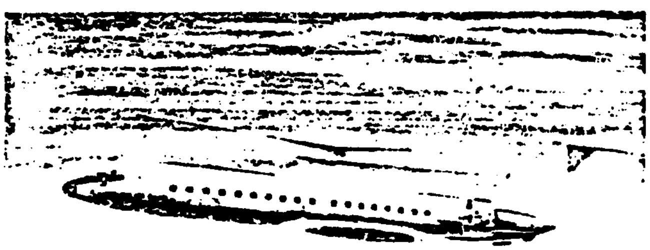


Helicopter RNAV instrument approach procedure to a point-in-space (MAP) for entry into the New York area from the south, southwest.

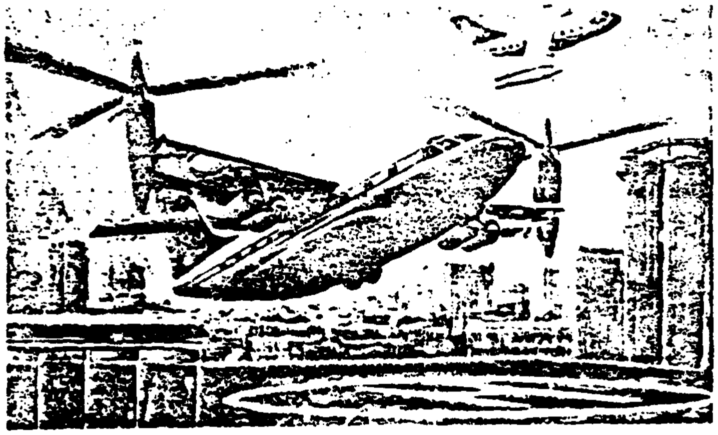
Advanced twin turbine executive/ business helicopter (in production).

Basic advancing blade concept (ABC) prototype helicopter.

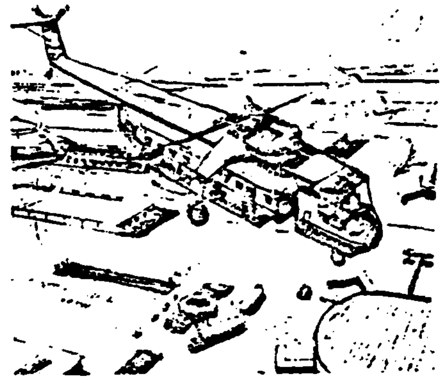




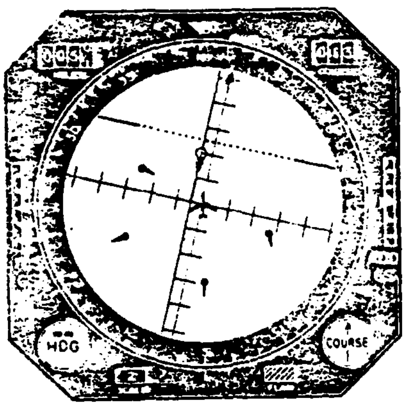
Advanced ABC compound helicopter (proposed).



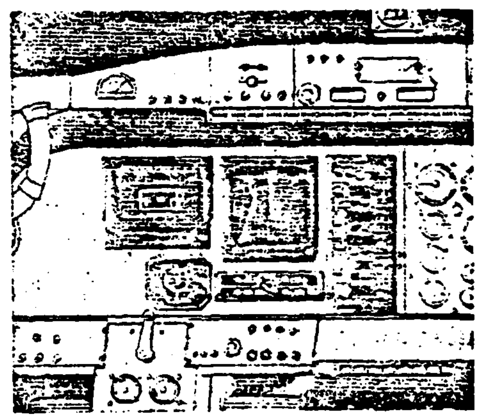
Tilt rotor advanced design helicopter.

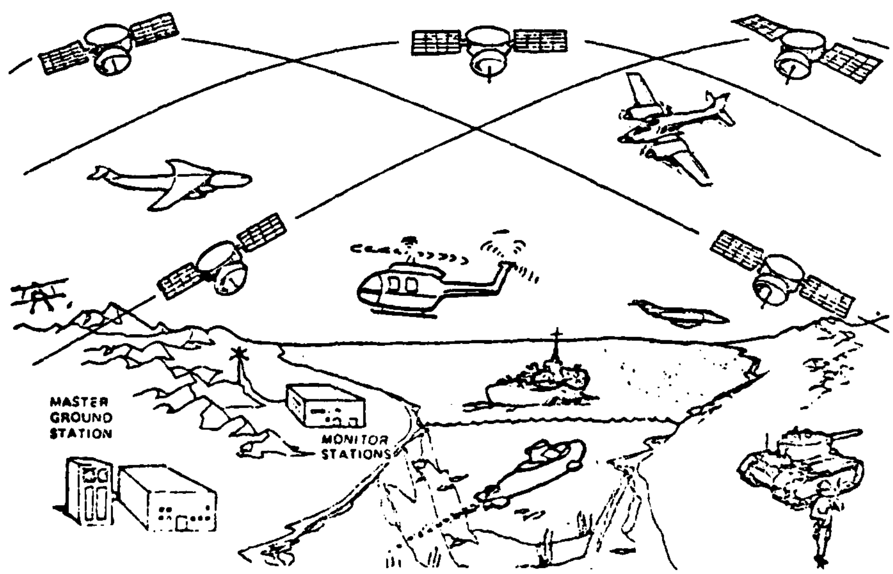


Concept of flying crane with mobile bus.



Concepts of electronic cockpit displays combining navigation and traffic situation information.





Satellite based precision three-dimensional navigation system (NAVSTAR/GPS) will greatly facilitate IFR helicopter/VTOL operations.

NEW ENGINEERING & DEVELOPMENT INITIATIVES --
POLICY AND TECHNOLOGY CHOICES

Chapter IV

APPENDICES

SAFETY AND FLIGHT CONTROL
Topic Group 4

APPENDIX B

A Sample of Survey Data Related to Coupled Approaches

During the latter part of 1977 and early 1978, the Airline Pilots Association conducted a survey among airline pilots to obtain information about the causes of missed approaches. Reasons included ILS problems, weather problems, equipment malfunction, ATC difficulties, and others.

A part of the information relates to the practical problems associated wtih use of coupled approaches in today's airline operations. A sample of comments given below reflect current experiences of this type:

"Vectored in too close and too high over fix - could not get stablized."

"Poor traffic control, improper spacing (close in vectors), speeds requested not within equipment capability."

"My concern is for sterility of approach path, re.: vehicles and aircraft close to ILS, also security of ILS facilities."

"Auto pilot did not function normally and was making excessive corrections. I believe this was caused by the turn on to the ILS at the marker. The auto pilot did not have time enough."

"This approach missed because ATC and/or approach control kept flight too high, too close in, and too fast (200 knots). Intercepted the LOC at angle which autopilot couldn't handle."

"Approach perfect to this (150' HAT) - aircraft dove 1,500 fpm...I'm suspicious of the amount of heavy equipment in use during low visibility as possibly having an effect on glide path accuracy."

"Vector and descent clearances are given as if visual approaches are being made. No opportunity to get aircraft stablized on LOC or G/P prior to final fix. Auto pilot is not capable of handling intercepts that vary between +90 degrees to -15 degrees. Autopilot has to be disconnected due to aircraft taxiing and taking off while on coupled approaches."

This sampling of comments simply represents typical operational problems. It is a small part of the total survey data. There is no statistical significance to the data nor has the selection been made with any qualitative objectives in mind.

APPENDIX C

Factors Affecting Pilot Decision Making

by

Air Line Pilots Association (ALPA)

Abstract: Contained in this appendix are suggestions to major areas of concern during the approach and landing, missed approach and takeoff flight phases.

MAJOR PROBLEM AREA: Human Capabilities and Limitations

TASK TITLE: INFORMATION REQUIREMENTS FOR COMPLEX OPERATIONAL DECISIONS

OBJECTIVE: To analyze critical flight phases to determine the information required by the flightcrew to make critical operational decisions in short periods of time.

REQUIREMENT: Several recent accidents were due to pilots making erroneous decisions during critical flight phases, such as takeoff, rollout, and approach to decision height. Although general rules exist to assist the pilot in making these decisions, such as V speeds and approach minimums, the specific information needed for realistic decision-making has not been determined. This task would develop these information requirements to support improved training of flightcrews in making operational decisions and to support improved procedural criteria that would be compatible with realistic human decision-making and information-processing capabilities.

SUGGESTED APPROACH: SRDS would award a contract for a detailed analysis of the information required by a flightcrew to make the following decisions:

1. Continue or miss at DH
2. Abort or continue a takeoff after V_1 when not field length limited
3. Stop or go around after float or rollout problems.

The information produced would be used to evaluate existing procedures for making these decisions, developing new procedures, and improving training in operational decision making.

APPENDIX C

Factors Affecting Pilot Decision Making

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Air Line Pilots Association (ALPA)

Abstract: Contained in this appendix are suggestions to major areas of concern during the approach and landing, missed approach and takeoff flight phases.

MAJOR PROBLEM AREA: Visual Segment Operations

TASK TITLE: IMPROVED LOW-VISIBILITY SIMULATION

OBJECTIVE: To encourage the development by NASA and industry of improved computer-generated visual illusions.

REQUIREMENT: Determination of the minimum visual cues needed to safely flare and land an aircraft, the impact of various approach aids (such as HUD and VASI) and the nature of visual illusions, continue to be problems partly due to a lack of capability to study the very low visibility environment in a controlled fashion computer-generated scenes offer the greatest potential for overcoming this problem, and the development of hi-fidelity scenes having this capability should be encouraged

SUGGESTED APPROACH: NASA would encourage through contracts the development by industry of the necessary video and computer capabilities to allow computer-generated scenes to be capable of hi-fidelity simulation of approach and runway environments down to CAT IIIA and B visibilities while still being able to [illegible] features, texture gradients, light brightnesses, nonhomogenity, and other realistic features of the low-visibility environment.

MAJOR PROBLEM AREA: Visual Segment Operations

TASK TITLE: <u>ASSESSMENT OF PILOT ATTRACTION TO VISUAL CUES</u>

OBJECTIVE: To assess the existence and nature of pilot attraction to visual cues, and find solutions to the problem of knowing when to revert to instrument references.

REQUIREMENT: Studies have indicated a strong reluctance on the part of pilots to give up visual cues, once acquired, and it has been suggested that unauthorized descents below MDA and continuance of approaches into dense fogs, with subsequent ground contact, may be attributed to this factor. This task would determine the validity of this premise and develop ways of minimizing its effect on the pilot.

SUGGESTED APPROACH: A simulator investigation of low-visibility landing would be conducted in which non-precision and precision approaches are performed into decreasing visibility and/or ceiling conditions. Pilot exceedences of established approach criteria and judgement in returning to instrument references would be documented for purposes of enlightening the pilot community to the existence and extent of these tendencies. Training and/or system improvements to alleviate the problem would be postulated and evaluated.

MAJOR PROBLEM AREA: Visual Segment Operations

TASK TITLE: EFFECTS OF MISSED APPROACH COMPLEXITY ON PILOT MENTAL SET

OBJECTIVE: To determine the effects of missed approach complexity on the predisposition of piltos to execute or not execute a missed approach under marginal conditions at decision height.

REQUIREMENT: The criteria that must be met in order to continue an approach at decision height are such that pilot mental set or predisposition could play a significant role in his decision under marginal conditions. This task would evaluate the influence of the complexity of the missed approach procedure on a pilot's decision to continue when a missed approach would be more appropriate.

SUGGESTED APPROACH: Line crews would fly simulated approaches in various weather conditions down to and below minimums with the missed approach procedure (MAP) as the experimental variable. The crews will not be aware that the MAP is the variable, the influence of the variable being determined by analysis of data for different crews on multiple approaches.

MAJOR PROBLEM AREA: Visual Segment Operations

TASK TITLE: EFFECTS OF PILOT EXPERIENCES ON APPROACH HABITS

OBJECTIVE: To determine the influence of pilot experiences on his predisposition to "duck under", carry excess speed, or develop other individual approach habits.

REQUIREMENT: Although generally operating within the bounds of published procedures, pilots occasionally develop mental sets based on their own experiences which influence their judgement and performance during approaches. This pilot mental set could be an important factor in many accidents where the pilot took some unexplained action that caused or contributed to the accident.

SUGGESTED APPROACH: The importance of pilot personal experiences with, such factors as wind shear encounters, hydroplaning, vortex encounters, crosswinds, slippery runways, etc., in determining his performance and judgement during approach and landing would be examined through interviews in which crews perform self analysis of the factors affecting their mental set, and through simulation of low-visibility approaches by populations of pilots specially selected to isloate these specific experiences and determine their effects on his performance.

MAJOR PROBLEM AREA: Procedures

TASK TITLE: CONTROL TRANSITIONS DURING APPROACH AND LANDING

OBJECTIVE: To determine the effects on crew performance of the landing task during late transitions from automatic to manual control.

REQUIREMENT: Oculometer studies of pilots flying manual approaches vs. monitoring automatic approaches have indicated different scanning behavior. This could mean that a pilot must transition from one type of information processing and mental integration to another when assuming control of an aircraft from an automatic system, which could imply logs in pilot performance during the transition. FAA and the airlines currently endorse use of autoland systems to lower altitudes for low approach minima. A need exists to determine whether a point in the approach exists beyond which pilots do not have time to adapt to manual control before performing the landing manuever.

SUGGESTED APPROACH: Additional oculometer data would be taken to verify scanning behavior differences. Basic laboratory & simulation experiments would be conducted to examine human performance of an ILS tracking type task just after manual control reversions. Finally, simulated landings in low visibilities would be performed with control reversion at 200 feet, 100 feet, 50 feet and after touchdown, measuring touchdown dispersion, sink rates, attitudes, ILS deviations, and rollout control.

MAJOR PROBLEM AREA: Cockpit Procedures

TASK TITLE: **EVALUATION OF REVISED CALLOUT PROCEDURES DURING APPROACH AND LANDING**

OBJECTIVE: Determine if identical VFR and IFR approach callout procedures would improve performance during the visual segment.

REQUIREMENT: Most airlines have different callout procedures for instrument and visual approaches. When a flightcrew acquires visual references during an instrument approach, reversion to VFR procedures occurs with some callouts omitted. It has been proposed by NTSB, and others, that use of IFR callouts on all approaches would prevent duck unders and other problems during the visual segment of an approach.

SUGGESTED APPROACH: A contract would awarded to an airframe manufacturer, such as Boeing, or an airline having good visual simulation capability. Line crews from an airline having different IFR and VFR approach procedures would perform multiple approaches under night and day, variable breakout heights, variable visibilities, and variable approach lighting system configurations. Tracking and touchdown performance will be measured and crew procedures evaluated by an observer and crew interviews.

MAJOR PROBLEM AREA: Human Limitations and Capabilities

TASK TITLE: PILOTS DECISION MAKING PROCESS DURING APPROACH AND LANDING OPERATIONS

OBJECTIVE: To perform a comprehensive scientific study which would lead to real solutions in the prevention of approach and landing accidents associated with decisions made in low visibility at decision height.

REQUIREMENT: ALPA has suggested that a human factors study of the procedures at decision height should be undertaken. There is a lack of information concerning the minimum visual frame of reference necessary to initiate a safe landing from decision height, in conditions of low visibility. This task would develop the criteria to furnish adequate visual reference to the pilot.

SUGGESTED APPROACH: NASA would conduct the program beginning with a background review of literature and accident/incident data bases to determine characteristics of operational decision making and factors that affect the pilot/crew decision process. Physiological and phychological testing would be performed to develop a better understanding of human information processing and decision making. Laboratory and simulation testing would follow to verify decision making models and the effects of various information sources. A full mission simulation would follow to evaluate decision making concepts developed during laboratory experiments in an environment with all information sources, operational constraints, and full crews simulated.

APPENDIX D

THE ROLE OF FLIGHT SERVICE STATIONS IN IMPROVING WEATHER INFORMATION PROGRAMS

Background

During the latter part of 1974, the principal general aviation organizations, operating under the umbrella of the General Aviation Advisory Committee (GENAVAC), developed a position paper on "Flight Services for General Aviation - A Plan for the Future." The participating organizations were:

Aviation Distributors and Manufacturers Association
Aircraft Owners and Pilots Association
Experimental Aircraft Association
General Aviation Manufacturers Association
National Association of Flight Instructors
National Air Transportation Associations
National Business Aircraft Association
National Pilots Association

These organizations have an intense interest as weather continues to be the second largest causal factor in general aviation fatal accidents with the largest factor being the pilot. Obviously, if the pilot had not flown into weather beyond his capabilities, the accident would not have happened.

The general aviation pilot is frequently faced with:

a. No weather information at his origin or destination.

b. No information on TOPS, icing, or other weather conditions which may be encountered in flight.

c. Spotty surface information even along heavily traveled routes.

d. Forecasts of minimum value because of their general nature.

Under these restraints, the pilot has little basis to decide if the flight can be made VFR. He decides to "try it." When the ceiling and visibility deteriorate, he may - in the absence of any real information - conclude that the condition is only local or temporary and continue. Sometimes that decision is fatal!

Obstructions to vision - i.e., low ceilings, fog and heavy precipitation - tend to trap general aviation pilots. Analysis of data provides a clear profile of a typical fatal accident involving a private pilot without an instrument rating who proceeds into an area of low clouds, fog or rain, may become spatially disoriented and collides with terrain, frequently out of control.

The general aviation organizations individually and collectively adopted a statement of weather requirements in 1974 to be used as a guide for developing programs to provide better weather information for pilots. The requirements were based on concepts that included:

a. methods of mass dissemination of preflight weather information are required.

b. All aviation weather reports, including in-flight reports made by any pilot, must be collected and disseminated.

c. Thorough aviation weather briefings, including forecasts and real time weather, must be available to all general aviation pilots.

In considering programs to meet general aviation weather requirements, the association considered:

a. Surface observations
b. In-flight pilot reports
c. Collection systems
d. Forecasts
e. Dissemination systems

Inasmuch as the Flight Service Station network plays a key role in weather observations, pilot reports, collection and dissemination, no consideration of these functions could be made without concurrently planning the future Flight Service System. Each factor was examined first, as to its contribution to general aviation safety, and second, as to its impact on the Flight Service System.

Surface Weather Reports

There are nearly 7,000 airports open to the public in the United States, but only about 850 of them have official weather observations. There are over 1700 airports with approved instrument approach procedures, but weather observations are available at less than half (793) of those airports. General aviation pilots are now authorized to make instrument approaches at 914 airports where no weather information is available.

The National Weather Service, the FAA and the aviation industry are each responsible for making observations at about one-third of the 850 airports. The Flight Service Stations take observations at less than 200 airports with FAA towers taking observations at slightly more than 100 airports.

Several obvious conclusions can be drawn from these bare statistics:

a. Many more surface weather observation points are required for general aviation. At the minimum, some weather information should be available at airports to which instrument approaches are made regularly.

b. It is impractical to expand the FSS network to provide government employees to take weather observations at all needed locations. Likewise, it is wasteful of resources to maintain an FSS at a location for the purpose of making weather observations if the observations can be made at less expense using automatic observing equipment or less costly arrangements for human observations.

The associations jointly signed identical letters to the Secretaries of Commerce and Transportation recommending the following elements as <u>minimum requirements</u> for observations at a single site on an airport:

a. Height of clouds at or below 5000'
b. Visibility or visual range
c. Wind direction and velocity
d. Temperature
e. Altimeter

The following additional elements are considered desirable, but not essential:

a. Dew point
g. Precipitation
h. Peak gusts
i. Average, trend and prevailing cloud height
j. Obstructions to vision

The minimum requirements were selected carefully to be acceptable for most operations and to be susceptible to relatively inexpensive automation. For example, "cloud height" and "visibility or visual range" were specified instead of the more complex "ceiling" and "prevailing horizontal visibility" elements now specified for official observations. Also, cloud heights above 5,000 feet were eliminated as automatic measurements grow increasingly difficult with height. The associations recognized that it might be considerable time before low cost automatic observing equipment becomes available and went on to say:

"Regardless of whether observing equipment is automated or not, the problem of equipment procurement for hundreds of airports owned by a multiplicity of local governments and private interests must be resolved. It appears to us that there is an easy and simple solution as the Aviation Trust Fund has an ever growing surplus paid in by the users, is dedicated to improving the airport and airway systems, and all concerned - the Congress, the government agencies, and the users - support the use of Trust Funds for capital improvement expenditures."

They recommended:

1. The FAA use its authority under the Airport and Airway Development Act to make grants to states, and other eligible bodies for the purchase of approved manual or automatic weather observing equipment.

2. The NWS be staffed to cooperate fully with any purchaser of weather observing equipment in providing training and certification of observers as required.

3. That the FAA field test simple cloud height and visibility measuring devices (such as automatic ceilometers and back-scatter devices_ to determine their operational usefulness if the measurements are read by incertificated personnel or the information is transmitted automatically to pilots or to a collection station.

4. To the extent the operational tests prove feasible, the FAA use "cloud height" and "visibility" to define landing and take-off weather requirements if appropriate to the type of operation involved.

Very little visible progress has resulted from these recommendations, although considerable discussion has followed, and research is oontinuing on automatic systems.

The FAA has a test of "AV-AWOS" (Aviation Automatic Weather Observing Station) underway at Patrick Henry Airport which shows considerable promise for major airports as it costs about $150,000. Individual elements of the AV-AWOS are being examined to seek less expensive combinations for general aviation airports and it is projected that a simpler system could be produced on the order of $50,000 to $60,000 <u>after</u> new cloud height measuring systems using laser beams are developed. <u>At the</u> present time, no satisfactory auto-

matic visible light systems are said to be satisfactory. It now looks like the best approach is to provide the 50 states with Trust Funds for manual observation equipment purchase and encourage the states to arrange with fixed base operators and other airport personnel for regular observations. Even this path is not clear as FAAP (Aid to Airports) Trust Fund money is over-subscribed for general aviation airports and many fixed base operators are reluctant to accept the additional responsibility. Nevertheless, some states, such as Maryland, have made progress in providing observations with state furnished equipment. The most successful approaches to date involve the use of "contract observers" where the National Weather Service pays for each observation and the use of airline personnel who are required to make observations for their own operations at some locations.

It is likely that observations will continue to be made under a variety of arrangements, but it is clear that the retention of an FSS at a specific location should not be based on the need for weather observations at that location.

In-Flight Pilot Reports

There are thousands of pilots aloft daily who, combined, observe virtually every square mile of weather from beneath, in it and above it. This potential source of weather information is virtually unused, except by the airlines, and the scattered reports that do originate from pilots perish rapidly in the ground system. Pilots rarely volunteer observations of weather encountered in flight because they believe the information is unwanted and they suspect it is used infrequently if offered. Controllers who do receive weather information rarely pass it on because there is no good system for doing so, and weather is of secondary importance in their book.

A bright spot in the PIREPS (pilots weather reports) picture has been the introduction of EFAS (Enroute Flight Advisory Service) at 43 flight service stations. EFAS has been described as the "party line" by radio where the pilots cooperate with each other and the FSS specialists by sharing weather information.

EFAS uses about 100 remote outlets and provides coverage at 5,000 above ground level, or below depending on line of sight to the transmitter, over most of the 48 states, and has proven to be of significant benefit. Its principal limitation is that its main participants are outside of the IFR ATC system and the vast amount of potential in-flight data from IFR flights never reaches EFAS.

PIREPS need to be given some priority status in the IFR system. Certainly, we do not want every pilot babbling endlessly about the weather encountered at every altitude and position, but we could have meteorologists in each Air Route Traffic Control Center responsible for identifying geographic areas and altitudes of interest and having controllers in those sectors solicit PIREPS from appropriate flights. It then should be the duty of the meteorologist to sort out, compress, massage and edit those PIREPS to formulate valuable, accurate and timely information concerning tops, layers, icing and turbulence and make that information available for rapid and widespread dissemination.

A tentative start in this direction is now underway as 13 of the 20 ARTCCs will each have three National Weather Service meteorologists assigned to them beginning on April 3, 1978 to cover 16 hours daily at each center. This should be the beginning of an effective PIREPS collection and dissemination program.

Collection Systems

The present weather collection and distribution system is a relic of World War II era communications technology and needs modernization urgently. Weather reports are collected and distributed on about 40 different 100 word per minute teletypewriter circuits which are too crowded to take much, if any, more information. If, by some magic, we could obtain the needed increase in surface and in-flight observations, the present system would be unable to collect and transmit them.

Large computers are now used to store weather information and limited use is made of high speed devices to obtain information for internal use by government personnel. Technology for improving the basic networks is available and is planned as part of the FSS modernization program.

Forecasts

At the present time, aviation weather forecasts are prepared in some 50 National Weather Service offices which are responsible for both aviation and non-aviation forecasting. The DOT estimates that one-quarter of the total NWS forecast costs are assignable to aviation terminal and area forecasts, and weather advisories. If only the manpower now used for aviation weather forecasting as a secondary activity of NWS foresast offices were assigned to Air Route Traffic Control Centers for the purpose of making all terminal and area forecasts based on real time information, imagine the quality of forecasts that could be realized with virtually no increase in cost.

Further improvements suggested by the associations are:

a. Update forecasts each hour based on hourly weather, pilot reports, and other information obtained from IFR flights.

b. Include tops, turbulence, winds, in-flight visibility and more specific route information in forecasts.

c. Make forecasts for two and four hour periods updated each hour.

d. Interconnect the various forecast centers with each other to have available current forecasts from all centers.

e. Provide for the forecast centers to contact any unicom airport to obtain lay or abbreviated weather information to assist in preparing route forecasts or in response to a pilot's query.

f. Rely more heavily upon satellite information with respect to frontal movements and cloud cover.

The National Weather Service has so far rejected these recommendations, but, perhaps, the assignment of NWS meteorologists at FAA expense to 13 centers is the first olive out of the bottle.

Dissemination Systems

Given needed surface and in-flight observations, collected and stored instantaneously, and perfect forecasts, the big problem of dissemination remains. At the present time, such information and forecasts as may be avail-

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able is distributed to pilots who make personal visits to flight service stations, call them by telephone for an individual briefing by a specialist, or scan yards of teletype paper at a fixed base office which provides a weather teletype. Some limited use is also made of telephone use radio recordings.

It has long been recognized that aviation can no longer afford the luxury of "one-on-one" briefings by a government employee prior to each flight and mass means of dissemination must be adopted. The associations concluded that service to the general aviation pilot would be improved significantly if:

a. A pilot could call from any telephone in the U.S. (i.e. from his home, office, or hotel room) and obtain a weather briefing upon which he could base a "go - no go' decision.

b. The weather briefing included the following items:

-- Forecasts
-- Hourly sequences
-- Winds aloft
-- Cloud tops
-- Turbulence
-- Icing conditions
-- NOTAMS

c. The pilot did not experience lengthy delays in reaching the telephone number nor be required to listen to a lot of information extraneous to his route of flight.

d. Aviation weather is presented twice daily on television so that front. areas and other graphical information could be seen in his home or hotel room.

e. The pilot had access to a weather forecaster, both pre-flight and in-flight, when special conditions required it or he needed additional information.

f. EFAS was available to provide the pilot with in-flight, real-time weather information,particularly on cloud layers, obstructions to visibility, turbulence and icing.

General Aviation Plan for Flight Service Station Modernization

The industry and the FAA have long recognized many, if not all, of the deficiencies of the system and there have been many schemes put forward to "improve" the system. In 1973, the DOT/FAA proposed a system consisting of 30 manned hubs which would feed some 3500 "pilot self briefing" outlets at airports for use by pilots desiring FSS services. The user groups rejected the plan as it relied too heavily upon use of automated self-briefing terminals located at airports and had no apparent tie-in with the IFR system for weather information. The FAA/DOT plan did provide for extensive use of modern computer and communications technology and made a case for concentrating FSS personnel in a limited number of highly automated hub locations.

The associations then formulated an alternative plan which was adopted by the FAA. The user plan called for:

a. consolidation of existing flight service radio communications for in-flight weather, NOTAMS and assistance into 20 hubs colocated with Air Route Traffic Control Centers.

b. EFAS to be a standard service at each consolidated facility

c. Remoting all radio and direction finding outlets to the consolidated facilities.

d. Providing automated pre-flight briefings by radio (TWEB) and telephone (PATWAS or voice response) type facilities.

e. Free access to the consolidated facilities from any telephone through "800" WATS service.

f. Separating teletype operating functions from flight service functions.

g. Transferring monitoring of navigation aids from flight service personnel to maintenance personnel.

h. Transferring weather observation responsibilities to NWS.

i. Elimination of airport advisory service and transfer of airport lighting control back to local airport officials.

j. Elimination of flight plan handling by FSS personnel.

In the meantime, the Congress directed that no additional closing of flight service stations be made except as necessary to conduct a test of a consolidated and colocated facility. Not more than five stations were to be consolidated for the test. The Washington ARTCC at Leesburg, Virginia was selected as the test site. Richmond and Charlottesville, Virginia, were consolidated with the Washington FSS at Leesburg and the facility provided with available automation equipment with had been provided to provide weather data to controllers.

The FAA has reported to the Congress that the "test" at Leesburg has demonstrated the advantages of automation and consolidation, but the advantages of colocation at a center site are not apparent. The user associations do not concur in the findings regarding colocation as the prototype operation has been neither complete nor satisfactory.

a. Only three stations were consolidated and the advantages of full-scale operation have not been tested fully.

b. The provision of toll-free service has been over-extended in Virginia and not made available in Maryland. Further, toll-free service was made available at Newport News and widely publicized in Virginia in competition with Leesburg.

c. Navaid monitoring was not transferred from the FSS to maintenance.

d. There was little apparent cooperation between the FSS and Center in obtaining PIREPS from IFR flights.

e. The advantages of "fast-filing" flight plans by automatically recording them by telephone were lost due to misplaced priorities in handling of recorded flight plans.

Despite these and other difficulties, there were many beneficial improvements. Recorded PATWAS information was improved significantly, briefings by

specialists were faster and more accurate due to computer technology, and productivity was increased by better utilization of personnel. Important to the successes was the hard work and enthusiasm of the facility chief and all the specialists assigned to Leesburg. The Associations believe that many of the deficiencies which developed at Leesburg are easily correctible and need not be repeated if the FAA provides adequate management attention within itself and educational information on the program to pilots and airport operators.

Current FAA Plans for FSS Modernization

The FAA issued a new "Master Plan" for Flight Service Station Automation Program in November, 1977. Funds for procurement of all required equipment are contained in the F.Y. 1979 Budget Request now pending before Congress.

The new master plan deviates from the previous plan principally by providing for two possible alternate final configurations, which are:

a. Consolidate and colocate the present 292 stations into 20 hubs at the 20 center locations. (The configuration recommended by the user associations and adopted by FAA)

b. Locate the major automation components at the 20 center locations and remote the automated equipment to a minimum of 43 to a maximum of 150 existing stations. The remaining 142 stations would not be automated and might, or might not, be closed or consolidated.

The FAA states that either plan will require approximately 1200 specialist display consoles. In the 20 hub plan, all equipment, displays and specialists will be in the 20 colocated hubs. In the alternate plan, the displays and specialists will be distributed in from 43 to 150 existing stations. In either case, the major computer systems will be in the 20 existing centers.

The FAA plan indicates the costs for both plans are practically the same through 1982. In either case, it is contemplated that computer systems will be installed at ARTCC Centers to drive specialist terminals at the 43 busiest flight service stations and will be fully operational by 1981. A decision on the final configuration need not be made until 1982/83. The FAA is thus able to postpone the hard decision concerning final configuration and will be able to introduce automation in the system at an earlier date than it would if it prepared the 20 sites to receive the consolidated stations prior to automating the system.

In either plan, the FSS personnel will provide: emergency assistance; EFAS; en route communication; pilot briefings; flight plan servicing; and NOTAM processing. As existing stations are part-timed or decommissioned, the weather observing function will be transferred to control towers, NWS, contract observers, or automated units.

In either case, emphasis will be placed on improved FATWAS service to eliminate the need for personal briefings from specialists in many cases. Also, provision will be made for direct access to computer weather data by both touchtone telephone or video tube input-output devices available to individuals or fixed base operators.

An interesting test of a pilot direct access to computer generated voice systems will be undertaken in the Washington area beginning in April 78.

APPENDIX E

June 20, 1977

JOINT LETTER

FROM

Aircraft Owners and Pilots Association
Aviation Distributors and Manufacturers Association
Commuter Airline Association of America
Experimental Aircraft Association, Inc.
General Aviation Manufacturers Association
National Association of Flight Instructors
National Air Transportation Associations, Inc.
National Business Aircraft Association, Inc.
National Pilots Association
(Addresses listed on Attachment No. 2)

TO:

The Honorable Juanita Kreps
Secretary of Commerce
Commerce Building
Washington, D. C. 20230

The Honorable Brock Adams
Secretary of Transportation
400 7th Street S. W.
Washington, D. C. 20590

Dear Madam Secretary:

Dear Mr. Secretary:

Weather has been cited as a cause or factor in four of every ten fatal accidents and two of every ten non-fatal accidents in general aviation for a number of years. We believe the general aviation accident rate could be improved substantially if accurate and timely weather information could be obtained readily by general aviation pilots.

Despite significant progress in satellite observation techniques, extensive computer and communications capabilities, and large efforts in research and development, there has been little progress in providing weather observations at the growing number of general aviation airports that have either, or both, a published instrument approach procedure or a large number of based aircraft.

A study made in 1976 by Mr. Samuel V. Wyatt for the Aircraft Owners and Pilots Association, entitled "Criteria for Weather Observations at General Aviation Airports", listed all airports with approved instrument approach procedures together with the weather observation services, if any, and the number of recorded IFR approaches made by general aviation aircraft. A tabulation of this listing revealed that of the 1707 airports with approved instrument approach procedures, 914 had no weather observation service. A more complete analysis chart is included as Attachment No. 1.

Page two

We recognize that it is neither economically feasible nor desirable to station U. S. government personnel (either FAA or NWS) at all airports where weather observations are required. Further, we recognize that training and certification of observers supplied by non-governmental organizations imposes a burden on the National Weather Service and is unattractive to airport management and fixed base operators due to costs involved for the purchase of approved observing equipment and supplying trained observers even though weather observations are colateral duties. Nevertheless, this system must be used until automatic observing systems become practical.

With the above in mind, we have jointly determined what we believe to be realistic minimum requirements for weather observations at general aviation airports. Our objective was to specify only those elements of weather that have a significant influence on safety and, where practicable, be susceptible to automatic observation with direct readout by uncertificated airport personnel such as airport "unicom" operators. We recommend the following elements as minimum requirements for observations at a single site on an airport:

a) Height of clouds at or below 5000'

b) Visibility or visual range

c) Wind direction and velocity

d) Temperature

e) Altimeter

The following additional elements are considered desirable, but not essential:

f) Dew point

g) Precipitation

h) Peak gusts

Page three

i) Average, trend and prevailing cloud height

j) Obstructions to vision

It should be noted that we do not include a requirement for either "ceiling" or "ground visibility" as defined in FAR Part 1. "Ceiling" requires either human estimation of whether clouds are "scattered", "broken" or "overcast", "thin" or "partial", "obscured" or not, and height of various layers of clouds. This requirement has long thwarted development of simple inexpensive automatic weather observing systems. Similarly, "ground visibility" also requires either human observation or a complex of automatic devices to determine the "prevailing horizontal visibility". We believe simple measurement of "cloud height" and "visibility" at a single point on an airport is an acceptable minimum for most operations and both weather elements are susceptible to relatively inexpensive automation. Certainly, tests of these concepts should be conducted to prove or disprove their operational feasibility.

Regardless of whether observing equipment is automated or not, the problem of equipment procurement for hundreds of airports owned by a multiplicity of local governments and private interests must be resolved. It appears to us that there is an easy and simple solution as the Aviation Trust Fund has an ever growing surplus paid in by the users, is dedicated to improving the airport and airway systems, and all concerned - the Congress, the government agencies, and the users - support the use of Trust Funds for capital improvement expenditures.

As you know, the Airport and Airway Development Act of 1970, including amendments of 1971, 1973 and 1976, provide for the grant of Trust Funds for the purchase of navigation aids as a part of "airport development" and also for direct purchase and installation of "airway facilities" by the Government. The definition of any "air navigation facility" in the Federal Aviation Act of 1958, includes ". . . any apparatus or equipment for disseminating weather information . . . " in addition to the more general definition of "any facility used in . . . aid of navigation." Weather observations make operations at any airport safer and any navigation aid serving that airport more useful. Further, a long term and continuing precedent for the classification of weather observing equipment as "air navigation facilities" has been established by the Congress in making appropriations to the FAA to purchase and install weather observing equipment at flight service stations and airport traffic control towers.

In view of the foregoing, we recommend:

1) The FAA use its authority under the Airport and Airway Development Act to make grants to states, and other eligible bodies for the purchase of approved manual or automatic weather observing equipment.

2) The NWS be staffed to cooperate fully with any purchaser of weather observing equipment in providing training and certification of observers as required.

3) That the FAA field test simple cloud height and visibility measuring devices (such as automatic ceilometers and back-scatter devices) to determine their operational usefulness if the measurements are read by uncertificated personnel or the information is transmitted automatically to pilots or to a collection station.

4) To the extent the operational tests prove feasible, the FAA use "cloud height" and "visibility" to define landing and take-off weather requirements if appropriate to the type of operation involved.

It is realized that this suggested program, if successful, will require more communications, dissemination and analysis capabilities than now exist. However, these problems are solvable. Increasing the number of general aviation airport weather observations will improve flight safety. In addition, other industries, such as agriculture and marine, should benefit by the provision of these additional hundreds of surface weather observations.

We will be happy to meet with you or your representatives at any time to discuss these ideas in more detail.

Sincerely,

Signatures on following page

John Baker, President
Aircraft Owners and Pilots Association

Robert J. Clark, President
by G. F. Quinby, Past President
Aviation Distributors and Manufacturers Association

Thomas S. Miles, President
Commuter Airline Association of America

David Scott, Washington Representative
Experimental Aircraft Association, Inc.

Edward W. Stimpson, President
General Aviation Manufacturers Association

Jean Scheerer, Executive Secretary
National Association of Flight Instructors

Lawrence L. Burian, President
National Air Transportation Associations, Inc.

John H. Winant, President
National Business Aircraft Association, Inc.

William H. Ottley, Executive Director
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Attachment A

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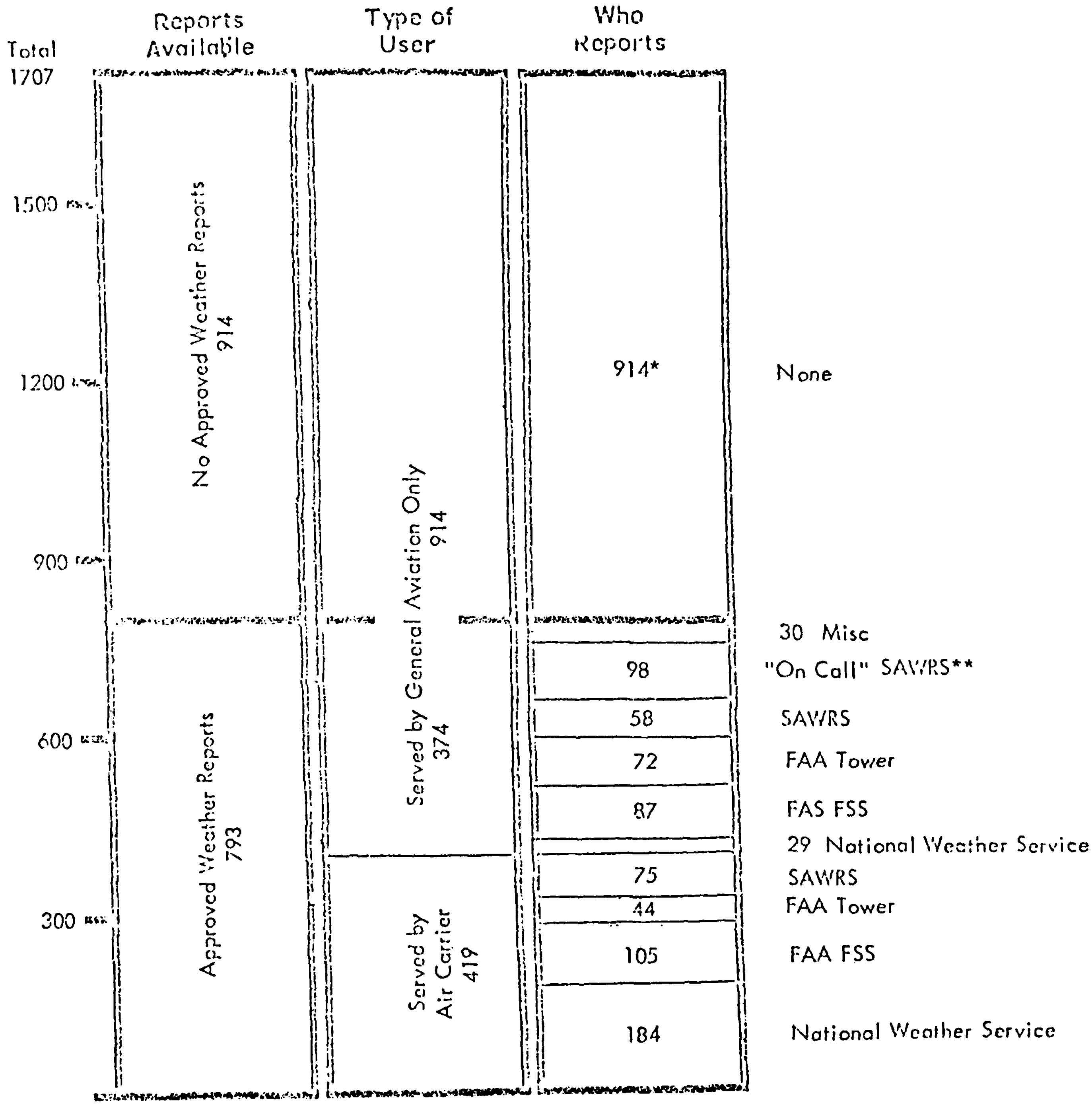

Source: Derived by David Thomas, GAMA, from data in AOPA report, "Criteria for Weather Observations at General Aviation Airports," by Samuel V. Wyatt

*Note: 190 of these have 1,000 or more instrument approaches annually; 374 have more than 50 I/

**SAWRS—Supplementary Aviation Weather Reporting Station

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